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THE CLOVER ROOT BORER[1]

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CONTENTS

	Page
Introduction	1
Synonymy	2
Habits of related species	3
Economic history	3
Europe	3
America	4
Distribution	6
Description	7
Egg	7
Larva	7
Pupa	8
Adult	8
Seasonal history	10
Early spring activity	10
Mating	11
Maturity of overwintered larvæ	11
Flight	12
Egg burrows	18
Larval and pupal development	19
Fall activity	20
Life history	20
Oviposition	20
Incubation period	22
Larvæ and larval mines	23
Life history—Continued.	
Larval period	25
Pupal period	25
Sexual development	26
Number of generations	28
Rate of reproduction	29
Ecology	31
Temperature	31
Moisture	31
Condition of host plant	31
Topography	32
Other host plants	33
Damage	35
First crop year	35
Second crop year	37
Injury to seedling clover	38
Natural enemies	38
Control	39
Control experiments	39
Field observations	41
Fertilizer	43
Repressive measures recommended	44
Summary	45
Literature cited	46

INTRODUCTION

The clover root borer, *Hylastinus obscurus* Marsham, an insect of European origin, is now present in almost all agricultural regions of the United States where red clover is an important crop. This insect is one of the principal factors limiting the life of a red clover stand after the first crop year[2] and has frequently caused large losses by

[1] *Hylastinus obscurus* Marsham; subfamily Hylesininae, family Ipidae, superfamily Scolytoidea, order Coleoptera.

[2] The term "first crop year" as used throughout this bulletin refers to the first calendar year following the year in which a given field of clover was seeded. Though a late crop of hay or seed is sometimes, under favorable conditions, obtained from a clover field seeded in the spring of the same year (*49, p. 20*[3]), this is usually not the case throughout most regions where red clover is grown.

[3] Numbers (*italic*) in parentheses refer to "Literature cited," p. 46.

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severe infestation of clover, even in the first crop year. It has been under observation for the last several years at the field station of the Cereal and Forage Insect Division of the Bureau of Entomology at Forest Grove, Oreg.[4] In the course of this investigation many new data on the bionomics of the insect have been accumulated. These observations are contained in this bulletin and an attempt has been made to correlate them with previously published records and with unpublished notes from the bureau files. The results of these studies are presented as a possible aid in the problem of successful clover culture. It should, however, be emphasized that insect injury is but one phase of a complex of factors affecting red clover as a crop.

SYNONYMY

The species was first described by Marsham (*31, p. 57*) as *obscurus* in the genus Ips De Geer, in 1802. The first description to be accompanied by biological notes was that of Müller (*32*), in 1807, who described it as *trifolii* in the genus Bostrichus of Fabricius, according to the title of his paper. Schmitt (*39*), in 1844, published descriptive and biological notes on Müller's species as *Hylesinus trifolii* Müller. Chapuis (*7, p. 231*) in 1873 placed Müller's species in the genus Hylastes (Erichson), and was followed in this classification by Eichhoff (*10, p. 97*) in 1881. Bedel (*3, p. 390*) in 1888 erected a new genus, Hylastinus, for Marsham's species (*obscurus*) and considered it synonymous with *trifolii* Müller. Hagedorn (*17, p. 7; 18, p. 43*) in 1910 made Hylastinus a subgenus of Hylastes and did not recognize Marsham's species, but retained the name *trifolii* Müller. Reitter (*36, p. 280*) in 1916 retained the genus Hylastinus and recognized the synonymy of *trifolii* with *obscurus* and also listed *Hy. crenulatus* Duft. as a synonym. The species was listed with descriptive notes by Swaine (*41, p 9*) in 1918 under the name *Hylastinus obscurus* Marsham. The more important synonymy is as follows:

Ips obscurus Marsham, 1802 (*31, p. 57*).
Bostrichus trifolii Müller, 1807 (*32*).
Hylesinus trifolii Müller (Schmitt), 1844 (*39*).
Hylastes trifolii Müller (Chapuis), 1873 (*7, p. 231*).
Hylesinus trifolii Müller (Riley), 1879 (*37*).
Hylastes trifolii Müller (Eichhoff), 1881 (*10, p. 97*).
Hylastinus obscurus Marsham (Bedel), 1888 (*3, p. 390*).
Hylastes obscurus Marsham (Davis), 1894 (*9*).
Hylastes (sub. g. *Hylastinus*) *trifolii* Müller (Hagedorn), 1910 (*17, p. 7; 18, p. 43*).
Hylastinus trifolii Müller (del Guercio), 1915 (*16, p. 263*).
Hylastinus obscurus Marsham (Reitter), 1916 (*36, p. 280*).
Hylastinus obscurus Marsham (Swaine), 1918 (*41, p. 9*).

[4] Valuable aid has been rendered by C. W. Creel, in charge of the Forest Grove station during much of the investigation, Max M. Reeher, James M. Langston, and Merton C. Lane, all of whom are, or at various times have been, attached to the station, and have aided in field observations and control experiments. The writer's thanks are also due to A. J. Pieters and H. A. Schoth, of the Bureau of Plant Industry, for cordial cooperation and interest; also to G. R. Hyslop, of the Oregon Agricultural College. E. A. Schwarz, of the Bureau of Entomology, with his usual kindness, assisted in the study of the synonymy of the species. E. E. Cowin, of Wapato, Wash., and William A. Hermens, of Verboort, B. H. Reeher, of Gales Creek, Menold Bros., of Cornelius, and Morris M. Goodrich, of Yamhill, all in Oregon, have aided materially in the work by their cooperation. Credit is given hereafter for the use of unpublished notes which have been of material assistance. Sadie E. Keen, of the Bureau of Entomology, has assisted in the preparation of the manuscript and tabular matter, and the writer is indebted to W. R. Walton, Entomologist, Cereal and Forage Insect Investigations, for suggestions regarding the matter included and for preliminary editorial work on the manuscript.

HABITS OF RELATED SPECIES

Hylastinus obscurus Marsham is the only representative of its genus known in America and is quite distinct in several ways from its near relatives in the subfamily Hylesininae of the family Ipidae of the superfamily Scolytoidea. Other members of its subfamily in America and Europe form characteristic egg galleries in the trunks or branches of trees or woody shrubs. Many of them prefer injured or dying plants to healthy ones, but several species have the reputation of attacking healthy trees on occasion. *Alniphagus aspericollis* Lec., which of western species is anatomically the nearest to *H. obscurus*, tunnels under the dying bark of western alder; *Hylurgopinus rufipes* Eichh. (*Hylesinus opaculus* Lec.), which also resembles *H. obscurus*, tunnels in the dying bark of elm and basswood in the eastern part of the United States. Reitter (*36, p. 280*) has described another species of *Hylastinus*, *H. fankhauseri*, which mines under the bark on the stems of the leguminous shrubs *Laburnum anagyroides* and *L. alpinum* in the mountainous regions of south-central Europe.

As the great majority of the Nearctic species of the Ipidae breed normally in the bark or wood of trees, the habit of *Hylastinus obscurus* of mining and breeding in the roots of herbaceous leguminous plants may be considered decidedly aberrant. It would seem from several apparently authentic European records that the species may occasionally have the habit, more normal to the subfamily, of mining under the bark on the stems of woody leguminous shrubs (Cytisus, Ulex, and Spartium), especially on plants which have been injured by frost or other agency. Some of these records may refer to *Hylastinus fankhauseri* Reitter, but the observers in a few cases, notably Bedel (*2*), were systematists with an extensive knowledge of the Ipidae, and their records can hardly be questioned without further study of the species collected on these host plants in Europe, especially as Reitter (*36*) retains *Spartium junceum* and *Ulex europeus* in his list of hosts of *H. obscurus* and records *H. fankhauseri* only from south-central Europe.

ECONOMIC HISTORY

EUROPE

Apparently *Hylastinus obscurus* has rarely attracted attention in Europe. Damage to clover serious enough to be noted in entomological literature has occurred in Germany and more recently in France and Italy. Müller (*32*) reported a very serious infestation of red clover near Mainz in the year 1803, which afforded an opportunity for studying the species. His report of conditions leading up to the outbreak, as given by Schmitt (*39*), is very interesting and informing. According to this account, the year 1802 was so dry and hot that much of that year's clover seeding was lost and the farmers, contrary to their custom, had left a large acreage of second-year clover for another crop. After an unfavorable spring in 1803, which probably thinned the clover stands, almost all of the remaining clover was destroyed by the root borer. Müller arrived at the opinion that the root borer was principally responsible for the dying out of clover the third year from seeding. Later (1844) Schmitt (*39*) studied the species in the same region and contributed further to our

knowledge of its life history. He disagreed with Müller as to the damage caused by the species and expressed the opinion that red clover under the system of culture in that region died out from natural causes in the third year, and that the root borer attacked only dying plants, as was the habit of its near relatives which attacked injured or dying trees. Bach (*1*) in 1849 confirmed the earlier observations of the two other writers as to the true host plant of the species.

In spite of these observations some controversy arose as to the true host of the species.[5] In 1869 T. Algernon Chapman (*6*) gave an interesting account of the occurrence, habits, and partial life history of what he determined as Marsham's species on furze (*Ulex europaeus*) and Scotch broom (*Cytisus scoparius*). He noted that usually only large stems of furze or Scotch broom were attacked; sticks which had been cut down were rarely attacked, but living stumps and stems of plants dying of age were often infested. He recorded the species as associated with *Phloeophthorus rhododactylus*. According to Løvendal (*29, p. 118*), Nördlinger, in September, 1850, found larvæ, pupæ, and adults of *Hylesinus trifolii* inside the thickest roots of 2 or 3 year-old red clover; but the plants, though apparently infested during the previous year, showed no sign of unhealthiness. In the clover the egg galleries were not regular, but Nördlinger also found the species breeding in arm-thick stems of *Cytisus* (*Spartium*) *scoparius* in September, 1855, at la Teste, near Bordeaux. In these shrubs the egg galleries were two-armed and horizontal, and had furrowed both the bark and the outer part of the wood. In 1876 Perris (*34, p. 175*), stated that *trifolii* was undoubtedly a misnomer and that he had never found the species on clover. Bedel (*2*) corrected this statement in the same year and named three hosts of the species (*H. trifolii*) belonging to three different genera of papilionaceous plants. Of these, *Trifolium pratense* was the preferred host near Paris, as in Germany. It was also found on (*Sarothamnus*) *Cytisus scoparius* in living stems of unusual size in Brittany, in company with a Phlocophthorus. Bedel also stated that he had found the insect on *Ononis natrix*, in an old woody root exposed on the side of a bank at Belmont. Cecconi (*5, p. 164*) in 1899 described galleries of what were determined as *H. trifolii* Müller in stems of *Cytisus alpinus* weakened by frost. Del Guercio (*16, p. 268*) reported in 1915 that red clover was damaged in Tuscany, and also noted the occurrence of the species (*H. trifolii* Müller) on *Cytisus laburnum*, but stated that he considered the individuals on *C. laburnum* to be a different biological race. Marchal (*30, p. 9*) reported injury to clover in the Gironde in 1913, and Wahl and Müller (*44, p. 35*) reported injury to red clover, probably by this species, in Baden in the same year.

AMERICA

The clover root borer is believed by all American authorities to have been introduced from Europe. It was not noticed by American entomologists as a pest until 1878, when Riley's (*37*) account of the insect in western New York was prepared. In all probability the insect had been present for many years. Henry (*19*) reported

[5] Some of this confusion may have been caused by failure to recognize the species afterwards described as *H. fankhauseri* Reitter, but for reasons already stated the writer hesitates to disregard all of these records.

that, on July 6, 1880, the clover root borer had taken all the clover in portions of Genesee County, N. Y. Lintner (*27, 28*) published notes on the species in 1880 and 1881. White (*50*) reported "incalculable damage" to clover fields near Edmonton, Ontario, June 9, 1888. Fletcher (*11*) reported damage to clover in Harwich Township, Ontario, in August, 1891. The clover root borer was first observed in Michigan in 1889, near the west end of Lake Erie, and became destructive in southern Michigan in 1893. Davis (*9*) made a study of the species in Michigan in 1893–94, and published original observations on its life history and control experiments. The insect was injurious in Ohio by 1890 and was recognized as a serious pest in the northwestern part of that State in 1893. Webster (*46*) made original observations on the species in Ohio, which were published in 1899, together with a report on control experiments. His account is probably the best that has been published on the species. Cordley (*8*) reported the occurrence of the clover root borer in Oregon in 1896. Folsom (*12*) made some original observations on the species in Illinois, which were published in 1909.

Unpublished records of the destructive work of the species, taken from the files of the Bureau of Entomology, are here noted. A. J. Porter, of Bern, Ind., reported September 24, 1905, that a whole field of clover had been destroyed since the last of June. W. J. Phillips, of the Bureau of Entomology, reported root borers in destructive numbers at Wellsburg, W. Va., in November, 1905, stating that the farmers complained of short clover crops for several preceding years. The same observer noted such severe injury at Defiance, Ohio, on August 22, 1908, as to lead a number of farmers to plow up their fields. The late E. J. Vosler, formerly of the Bureau of Entomology, reported serious injury to red clover near Murray, Utah, in August, 1911. A. F. Satterthwait, of the Bureau of Entomology, reported serious injury by root borers near Van Wert, Ohio, on June 17, 1915, but in this case a fungous disease and possibly other factors were also involved in the failure of the clover crop. Virgin Browning, of McClure, Ohio, June 25, 1915, reported the clover-hay crop ruined by clover root borers. The description of the injury in this case also indicates that fungous disease may have been an important factor in the damage. H. L. Parker and W. E. Pennington, of the Bureau of Entomology, reported serious damage to clover in western Maryland in 1915 and 1916.

THE PACIFIC NORTHWEST

Red clover was not generally grown in the Willamette Valley of Oregon until the eighties and early nineties (*24, p. 3*), when decreasing yields of cereal crops under continuous cropping or occasional summer-fallowing led many farmers to rotation of crops with red clover included in the rotation as the best-paying legume. The red-clover crop became very profitable to western Oregon farmers as, besides its other advantages, excellent seed yields were obtained (*23, p. 4*). Until recent years clover stands remained productive for several seasons, but at present it is not usually profitable to maintain a clover stand for more than one crop year. The clover root borer is largely responsible for this failure of clover to withstand more than one cropping in western Oregon and Washington. There have also

been many instances of very severe damage to clover in the Willamette Valley, even during the first crop year. This pest first attracted attention in Oregon about 1895, as Cordley (*8*) noted its occurrence under date of March 24, 1896. It therefore was present even in the early days of red-clover culture in Oregon.

Clover culture for hay and seed was introduced on the Yakima Indian reservation of Washington within recent years. All the clover pests of the Willamette Valley soon became prevalent there, particularly the clover root borer. It is thought that the pest was introduced into this section with Willamette Valley hay used at the construction camps of the irrigation project.

The only section of the Pacific Northwest where clover is largely grown and where the clover root borer has not yet been found is the clover-seed section in the Twin Falls region of Idaho. This region was settled before the advent of the railroad and has always raised

FIG. 1.—Distribution of clover root borer in the United States, as recorded in the literature. The insect is probably more generally distributed in the northern part of the United States than is here indicated

a surplus of hay, so that probably no hay has ever been imported into the region. In this section clover stands have often remained productive for several years, although recently injury by nematode worms is leading to the adoption of a shorter rotation.

DISTRIBUTION

According to information compiled from various sources, the clover root borer is now found in Russia (Kief); Germany; Austria; Czechoslovakia; France; England; Canary Islands; Denmark; Italy (Tuscany); Canada (southern Quebec and Ontario); in the northern portion of the eastern United States, from western Maryland, West Virginia, Pennsylvania, Ohio, Indiana, Illinois, and Iowa, to the Great Lakes, and covering a portion of New England; in Utah (Salt Lake Valley); in Idaho (Boise, Moscow); in Washington (Pullman, Yak-

ima Valley, western Washington from Oregon to the Canadian boundary); and in western Oregon, at least as far south as Medford. Figure 1 presents the known distribution in the United States.

The wide distribution of this species over regions of the world where red clover is a common crop and its early appearance in most new clover regions would indicate that the species is readily transported by commercial intercourse. Root borers may be transported in hay shipments, because the beetles are sometimes found mining in the stems of clover, and, in cases of severe infestation, the clover tops and even portions of the root crown may be pulled out by the mower and become part of the hay. Adult root borers may also be transported in soil taken from the vicinity of clover plants, and in other ways during the period of flight, when they are often found in unexpected places.

DESCRIPTION

EGG

The egg (fig. 2) is short-oval in shape, with one side somewhat less rounded than the other, pearly white in color, smooth and glistening. Eggs in which development has begun are transparent at one end, because of retraction of the egg contents; whereas the fresh eggs are altogether opaque. The egg measures 0.67 mm. long by 0.43 mm. wide at the widest part. Eggs are found in niches, which are plugged with wads of frass, in the walls of the egg galleries.

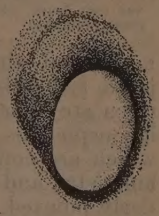

FIG. 2.—Egg of clover root borer, × 28 diameters

LARVA

FIG. 3.—Larva of clover root borer, lateral view, ×16 diameters

The mature larva (fig. 3) is of the usual scolytid type, short subcylindrical, wrinkled, and legless. The thoracic region is distinctly larger than the abdominal region, which tapers gradually posteriorly. The body setæ are short, fine and sparse, very obscure. The color is creamy white, with straw-yellow to light-brown head capsule and red-brown, triangular, dark-tipped mandibles, which have two broadly blunt teeth at the apices. The immature and still feeding larvæ appear dirty white or gray, because of the contents of the intestinal tract. The setæ of the head are light colored, fine, somewhat longer than the body setæ. The head capsule (fig. 4) has the epicranial suture [6] strongly impressed; front with a convexity anterior to the middle, with oblique ridges extending above to the sutures of the front on either side and below to the angles of the epistoma, forming concavities between the ridges. Front with posterior apex subacute. Labrum with raised

[6] The anatomical nomenclature here used is for the most part that of A. D. Hopkins, in his treatise on the Genus Dendroctonus (*20*).

median triangular area, truncate, or faintly emarginate. Clypeus with raised W-like rugosity with corresponding lateral and anterior mesial concavities; anterior margin truncate or obscurely broadly emarginate. Mature head capsules in pupation chambers vary greatly in dimensions, the minimum being 0.55 mm. long without mandibles, front 0.31 mm. by 0.29 mm., epistoma 0.23 mm., pleurostoma 0.12 mm.; the maximum 0.70 mm. long without mandibles, front 0.36 mm. by 0.34 mm., epistoma 0.28 mm., pleurostoma 0.15 mm.

The larva differs from the larva of *Sitona* sp., also found on clover roots, in being relatively smaller and stouter, without long hairs, and with more evident distinction between the thoracic and abdominal regions. Sitona larvæ are always external feeders, *H. obscurus* larvæ always internal feeders.

FIG. 4.—Head of larva of the clover root borer. Front view, greatly enlarged

PUPA

The pupa (figs. 5 and 6) is truncate fusiform in shape, with the apex of the abdomen squarely truncated on a line between the caudal spines on the ninth abdominal segment. The wing pads extend to near the hind margin of the sixth, and the elytral pads to near the hind margin of the fifth abdominal segment. The color of the fresh pupa is pearly white to white and shining. Setæ on all parts of pupa are short, fine, inconspicuous. Setal spines are also short and inconspicuous, except the two anterior dorsal spines on the prothorax, which are considerably more prominent than other thoracic spines and setæ, and the two very prominent conical, slenderly pointed, and slightly recurved caudal spines on the ninth abdominal segment. The two frontal setal spines opposite the upper inside margin of the eye mark the vertical limits of carinæ which form the outside margins of crescent-shaped concave areas. There is also a median inverted V-shaped concavity just above the pseudolabrum on fresh pupæ. The sculpture of the head varies with the age of the pupa. Anterior and middle femora with two setæ of unequal size on small papillæ. Elytral pads rugose.

FIG. 5.—Pupa of clover root borer. Ventral view, × 16 diameters

The pupa becomes pigmented as it matures; the eyes and mandibles become red-brown; wing pads dusky; the area around the mouth parts shows faint chitinization; later the face, legs, prothorax, and elytral pads assume a faint brownish tinge. The size varies considerably, typically 2.5 mm. to 2.7 mm. long by 1.1 mm. wide. The pupa is found in a pupal chamber at the end of the larval mine inside of the clover root.

ADULT

The body of the adult (fig. 7) is oblong oval; pronotum slightly wider than long, a little narrower than elytra, sides rounded, unarmed, strongly arcuate, narrowed roundly anteriorly, without anterior constriction dorsally; head visible from above; elytra deeply striate but unarmed except for shagreening posteriorly and laterally, roundly con-

vex posteriorly. The face, prothorax, elytra, legs, antennæ, and venter are distinctly clothed with short golden-brown hairs, hairs longer on venter than on dorsum; side pieces of mesothorax and metathorax; that is, the metathoracic episternum of Hopkins and mesothoracic episternum and epimeron, clothed with oval, gray or silvery, fringed scales. The convex head is finely and shallowly punctured with a faint transverse median impression at the base of the short beak. The antennæ, whose scrobes are distinctly separated from the front of the elliptical eyes, have a 7-segmented funicle, about as long as the distally inflated scape, and a short oval-connate, slightly compressed club, of which only the first suture is strongly chitinized and distinct, the first and second segments about equal and each longer than the third and fourth together. Swaine (*41, p. 43*) stated that the proventriculus has—

a short diagonal band of small costal teeth backwards from base of bristles, almost obsolete on disc which is not finely granulate; ligula widened distally and truncate at tip.

FIG. 6.—Pupa of clover root borer. Dorsal view, × 16 diameters

The prothorax is closely and deeply punctured, punctures irregular in size and shape, with a tendency to rugosity, vestiture of hairs short, fine, obscure. Median line absent, or present and more or less interrupted and obscure, usually vestigial, scarcely elevated if at all when present, marked by dividing line between prothoracic hairs even when not otherwise evident. Elytra clothed with three types of vestiture, punctures of striæ large, deeply indented, and tending to rectangular, each with a very fine, appressed, obscure, pale hair; interspaces more finely and obscurely punctured, punctures well separated, each accompanied by a single, coarse, brown, backward-directed scalelike hair. The interspaces are roughened between and around punctures, becoming shagreened or granulate posteriorly and laterally, and sparsely clothed with shorter golden-brown appressed scalelike bristles. Interspaces and striæ almost straight. Ventrally, the anterior coxæ are widely separated and clothed with long golden hairs, the second visible ventral abdominal segment, or sternite 4 of Hopkins, about as long as the fifth, or sternite 7 of Hopkins, and nearly double the third, or sternite 5 of Hopkins. Venter and legs shallowly and evenly punctured and clothed with hair. The tibiæ are toothed and dilated, the anterior pair with exterior angle of anterior margin nearly rectangular, with four short, blunt, recurved teeth close together on anterior margin and a stronger lateral tooth usually posterior to others on outer margin; the median pair have three strong teeth along anterior half of outer margin; the posterior pair have two well-separated strong teeth along outer margin. The third joint of the tarsus is deeply bilobed.

FIG. 7.—Adult of clover root borer, × 30 diameters

The color of the adult varies with age and hardness. The fresh callow adult is almost cream-colored and requires several days to become chitinized. As the insect hardens the color ranges through dull yellow and various shades of red-brown. The old, fully matured adult is a very dark pitch-brown, sometimes almost black; the head, prothorax, sides of body, and venter always a shade darker than the elytra, which almost always have a distinct red-brown tinge, even when very dark. The legs and antennæ are light red-brown, the antennæ paler on club. Eyes and mandibles black in the mature form. The smallest specimen seen measured 1.82 mm. long by 0.82 mm. wide; the largest measured 2.5 mm. by 1.18 mm. The average is about 2.2 mm. by 0.92 mm.

Secondary sexual characters are very obscure; the male head tends to be narrower than the head of the female. There are apparently no reliable characters for distinguishing between living males and females.

SEASONAL HISTORY

EARLY SPRING ACTIVITY

Clover root borers usually pass the winter well down in the roots of the clover plants on which they were nourished during their larval life of the preceding season. The great majority at this time are fully matured adults and remain more or less dormant, either singly or in small groups, in enlargements of the larval mines. Adults which for any reason have become separated from clover roots may pass the winter in the soil or, rarely, under trash on the surface of the ground. Occasional larvæ, usually well grown, are found during the winter in larval feeding burrows. Apparently these are larvæ which hatched from eggs laid in the late summer of the preceding year.

When the soil warms up to a temperature of about 45° F.[7] in the early spring, the activity and feeding of the adults and the few overwintered larvæ are gradually resumed in the roots. More or less activity probably occurs also during the winter when temperatures are high enough to permit of metabolism. The adults work their way from the lower parts of the roots towards the crown, where they are often found congregated in March and April. They feed on the root tissues and their so-called fat bodies begin to develop. As the soil temperatures rise above 50° F. this activity becomes more pronounced, and when the temperature of the air at the surface of the ground is between 55° and 60° F. the borers often leave the roots and walk about. This form of activity may rarely take place on warm days in February, from plowed-up clover and dead clover roots, but usually occurs in late March or early April and on days later in the spring when air temperatures range below 65° F. In case of a cool, backward spring, this movement of the beetles on foot is the only method of migration to new host plants until late in the season.

In clover fields plowed up during the preceding summer and fall, soil conditions, and the disturbed, abnormal state of the residues of the clover root borer's host plant, induce premature activity of the

[7] Temperatures for field observations were recorded from portable air temperature thermometers and portable soil thermometers. Observations made on the laboratory grounds were correlated with standard Weather Bureau maximum and minimum thermometers, a Friez hygrothermograph, and a Friez soil thermograph, the bulb being buried 3 inches under growing winter wheat.

adult borers, which attempt migration in response to the stimulus of the first warm days of late March. In 1919, root borers were swept as early as March 29 from winter wheat which had been seeded on clover sod the previous fall. This was three weeks earlier than the emergence of beetles from undisturbed clover. On February 25, 1921, six weeks earlier than the first flight from undisturbed clover, Max M. Reeher noted a root borer crawling on the ground in a wheat field seeded on clover sod. That this unseasonable activity is detrimental to survival is indicated by the writer's unsuccessful attempts to start outdoor colonies in cages much earlier than the normal period of flight.

MATING

The first mating is believed to take place in the spring during the time just previous to flight. Copulation at this time probably occurs in the hibernation chambers in the roots of the host plants, on the clover crowns, and on the surface of the ground. Whenever in the writer's experiments males and females were brought together at room temperatures during this season, or even in the fall, mating or attempted mating was observed. Mating in the field has been observed very rarely, although Schmitt (*39, p. 394*) stated that near Mainz the beetles are often found in copula and resting on clover plants at the end of April and beginning of May. The writer observed one case of mating in an enlarged larval burrow of the previous year in an old clover root dug up in the field on May 13, 1915. An attempted mating (unsuccessful) was observed on the surface of the ground on April 24, 1918, when the temperature at the surface was 62° F. A case of mating in a cage in the laboratory was more closely observed. In this instance the male appeared to choose a female whose head and part of the prothorax were concealed in a superficial burrow. The male established connection after about 10 minutes' endeavor. Copulation lasted 25 minutes, with very slight movement on the part of either, the female discontinuing feeding during the process. All other cases of mating observed in cages occurred either remote from the roots or on the exterior of the roots. The observed facts that females predominated in the first flights, and that all but a very small percentage of them had been fertilized before capture in flight, are also indicative of a general mating previous to the first spring flight.

MATURITY OF OVERWINTERED LARVÆ

The overwintered larvæ resume feeding in their burrows as the temperature permits and, according to records of observations made in various parts of the country, usually reach maturity, pupate, and become adults in May, sometimes as early as April or as late as June. Webster (*46, p. 144*) reported overwintered larvæ in Ohio as late as May 27, and a pupa of an overwintered larva on May 31, 1898. E. J. Vosler noted, at Murray, Utah, a large percentage of overwintered larvæ in April, and pupæ, apparently from overwintered larvæ, on June 6 and June 20, 1912. Overwintered larvæ have been found as late as May 17, 1915, at Forest Grove, Oreg.

FLIGHT

When the temperature of the air rises above approximately 65° F. migration of the adult borers may take place by flight. At such a temperature borers have been seen to climb grass stems and clover tops and prepare for flight. Few beetles fly, however, until an air temperature of 70° F. or more is attained. The time of the first spring flight is variable, depending on whether the soil temperature has been high enough to induce activity within the roots for some time previous to the rise of temperature above the critical point for flight. In the Pacific Northwest the times of occurrence of soil and air temperatures sufficient to induce flight are exceedingly variable from year to year, and these conditions have an important bearing on the early infestation of new clover fields, and the resultant damage.

The earliest recorded first flights of beetles from undisturbed clover in the Pacific Northwest were observed April 7, 1916, and April 8, 1921, at Forest Grove, Oreg. Late records for earliest spring flight were, in the case of backward seasons, May 8, 1917, and April 26, 1920, also at Forest Grove, and May 5, 1917, at Wapato, Wash. According to records of the Hagerstown, Md., field station, made by H. L. Parker, the first spring flight probably occurred about the second week of April in 1915 and in 1916. Webster and Mally recorded April 26 as the date of first flight for the season of 1899 at Wooster, Ohio. Davis (*9*) reported the first capture in flight on May 3, 1893, probably near Lansing, Mich. E. J. Vosler reported the first borers in flight on May 18, 1912, at Murray, Utah. Schmitt (*39, p. 394*), of Mainz, Germany, reported adult root borers in greatest abundance above ground at the end of April and the beginning of May. Del Guercio (*16, p. 265*) stated that in Tuscany movement of borers begins about the middle of April in a mild year, or, in the contrary case, towards the end of that month. Eichhoff (*10, p. 97*) reported swarming of this species before and about the middle of June at Mülhausen, Alsace.

In Oregon favorable temperatures usually occur in the afternoon between 1 and 6 p. m. during May and June, and similarly at Murray, Utah, according to Vosler's notes. Eichhoff (*10, p. 4*) noted that at Mülhausen, Alsace, bark beetles, including clover root borers, were in flight in summer and fall only during the afternoon hours. The optimum temperature for flight appears to be 70° to 80° F. In the Pacific Northwest, because of unfavorable weather conditions, the normal flight period is often interrupted for several days at a time. The time of maximum flight, therefore, is usually several weeks later than the first flight of the earliest adults, and, in the Pacific Northwest, often occurs in May. The maximum flight at Forest Grove, Oreg., in 1916, occurred about May 2; in 1917, a backward season, about May 28. The maximum flight is of comparatively short duration, and there is a rapid dropping off in flight records after the maximum is passed. Scattering adults are rarely taken in flight as late as July. The latest recorded date for the Willamette Valley is July 14, 1915 (M. M. Reeher sweeping), and for the Yakima Valley in 1917 it was June 18 (one observed by E. E. Cowin, on screen).

The period of flight appears to be a time of great restlessness among the adults. The beetles do not settle upon the first plant on which

they alight but usually maneuver to the highest point on the plant and again essay to fly, not always successfully, as they are clumsy in taking off. Negative geotropism is very pronounced at this time, so much so that if two root borers happen to climb the same grass blade, the second will climb upon the back of the first as the highest available point. This tendency is closely related to the temperature; and even the obscuration of the sun by a cloud will often cause borers which have climbed plants to turn and descend to the ground. Observations indicate that borers commonly fly from 6 to 10 feet above clover fields, usually against the wind. Their flight is fairly straight and not rapid.

Females predominate in the early days of flight, being frequently 85 to 95 per cent of those collected. Of these, more than 90 per cent were found to have been fertilized before capture. In 1921, when a careful count by sexes of those collected was made, males

FIG. 8.—Small bannerlike screen covered with sticky tree-banding material and used in flight experiments

became more numerous (68. 6 per cent of the total catch) than females on May 13, near the time of maximum flight.

FLIGHT EXPERIMENTS

As flight is the principal means of interfield dissemination of root borers, and as the time and extent of infestation of clover fields in the first crop year are therefore almost entirely dependent on habits of flight, this phase of root-borer activity was given special attention. Experiments with flight screens coated with sticky tree-banding material were conducted near Forest Grove, Oreg., in the humid Willamette Valley, and near Wapato, Wash., in the irrigated Yakima Valley. Screens of two types were used, the first being small and bannerlike (fig. 8), 18 or 24 inches wide by 3 feet long, placed on poles stuck in the ground and anchored by guy wires or nailed to

FIG. 9.—Full-length view of 50-foot screen used in flight experiments

FIG. 10.—Windlass used to reel in 50-foot screen

fence posts; the second of similar width but 50 feet long (fig. 9), raised between two wooden poles and reeled in on a windlass (fig. 10) for examination. As a rule counts were taken during the morning hours, when root borers were not flying. These experiments afforded some of the data on flight which have already been given. Tables 1 to 3 [8] summarize the more important experiments with these two types of screens.

TABLE 1.—*Counts of clover root borers caught on screens 24 by 36 inches, erected on the four sides of an infested field at Wapato, Wash., on April 2, 1917*

Date	Time of observation	Temperature at time of observation	North screen			East screen			South screen			West screen			Total for field
			North side	South side	Total	East side	West side	Total	North side	South side	Total	East side	West side	Total	
1917		°F													
May 3	2 p. m.	58	0	0	0	0	0	0	0	1	1	0	0	0	1
5	3 p. m.	68	1	2	3	1	0	1	1	2	3	2	0	2	9
7	5 p. m.	74	3	5	8	4	1	5	23	8	31	3	0	3	47
8	10 a. m.	86	1	2	3	1	2	3	8	8	16	2	0	2	24
10	3.30 p. m.	78	4	5	9	2	4	6	19	14	33	3	0	3	51
12	2 p. m.	70	4	2	6	0	0	0	7	2	9	0	0	0	15
14	4.30 p. m.	64	0	1	1	0	0	0	5	2	7	0	0	0	8
16	12.30 p. m.	56	0	0	0	0	1	1	2	1	3	0	0	0	4
18	9.30 a. m.	63	1	0	1	0	1	1	2	1	3	0	0	0	5
20	9.30 a. m.	----	1	0	1	0	0	0	1	1	2	0	0	0	3
22	----------	----	0	1	1	0	0	0	0	2	2	1	0	1	4
26	4 p. m.	72	1	2	3	0	0	0	0	2	2	1	0	1	6
28	4 p. m.	80	0	0	0	0	0	0	2	0	2	0	0	0	2
30	4 p. m.	70	1	1	2	0	1	1	3	1	4	0	0	0	7
June 1	4 p. m.	56	1	0	1	0	0	0	2	1	3	0	0	0	4
3	4 p. m.	76	0	0	0	0	0	0	1	0	1	0	0	0	1
16	3 p. m.	86	0	0	0	0	0	0	1	0	1	1	0	1	2
18	2.30 p. m.	91	0	0	0	0	1	1	0	0	0	0	0	0	1
Total	----------	----	18	21	39	8	11	19	77	46	123	13	0	13	194

Table 1 presents the counts of clover root borers caught on screens measuring 24 by 36 inches, at Wapato, Wash., in the season of 1917. The screens were erected one each on the north, east, south, and west sides of an infested field, and were examined (usually) every second day from April 2 to June 18, except on May 24. From April 2 to May 1 and from June 4 to June 15 no borers were found on the screens. The temperatures at the time of examination are recorded for the days on which borers were found. During April the temperatures on the dates of examination ranged from 38° to 64° F.

From an examination of the table it may be seen that in the case of each screen the side turned toward the field collected in the aggregate more borers than the opposite side, as was to have been expected; and that the screen erected at the south side of the field caught more than the other three combined. The borers counted on May 7, 8, 10, and 12 total nearly 71 per cent of the entire catch.

[8] The screens at Wapato were examined by E. E. Cowin; those at Forest Grove by C. W. Creel, M. C. Lane, M. M. Reeher, J. M. Langston, E. J. Taylor, and the writer. The screens were designed by C. W. Creel.

TABLE 2.—*Counts of clover root borers caught on a screen 24 inches wide and 50 feet high, erected April 22, 1916, at the eastern edge of a field of spring-plowed clover near Forest Grove, Oreg.*

Date of count	Height (in feet) of section of screen										Total
	0 to 10		10 to 20		20 to 30		30 to 40		40 to 50		
	East side	West side	East side	West side	East side	West side	East side	West side	East side	West side	
1916											
Apr. 25	0	2	0	0	0	2	0	0	0	0	4
May 2	7	5	8	13	3	3	0	4	2	3	48
13	9	35	18	36	13	4	7	2	5	11	140
24	4	3	2	5	1	0	0	0	3	3	21
July 24	0	1	0	0	0	0	0	0	0	0	1
Total	20	46	28	54	17	9	7	6	10	17	214

TABLE 3.—*Counts of clover root borers caught on a screen 18 inches wide and 50 feet high, erected May 1, 1917, at the western edge of a field of spring-plowed clover near Forest Grove, Oreg.*

Date of counts	Height (in feet) of section of screen										Total
	0 to 10		10 to 20		20 to 30		30 to 40		40 to 50		
	East side	West side	East side	West side	East side	West side	East side	West side	East side	West side	
1917											
May 2	0	0	0	0	0	0	0	0	0	0	0
7	1	0	0	0	0	0	0	0	0	0	1
10	5	0	4	1	7	0	6	0	3	0	26
15	0	0	0	0	0	0	0	0	0	0	0
22	11	1	4	0	4	0	2	1	1	0	24
24	70	1	27	1	24	1	9	0	7	0	140
29	237	28	147	15	102	23	63	7	37	4	658
31	7	1	1	0	2	3	0	0	3	4	21
June 12	7	1	28	3	14	2	7	0	11	0	73
27	1	0	0	0	0	0	0	0	2	0	3
Total	339	27	211	20	153	29	87	8	64	8	946

A long screen 24 inches wide and 50 feet high was erected April 22, 1916, at the eastern edge of a recently plowed clover field near Forest Grove, Oreg. To facilitate the counts of borers caught at different heights above the ground the screen was divided into sections of 1 foot each, beginning at 3 feet (the height of the windlass from the ground). A count was made on April 25, only 4 borers being found, all on the west side of the screen. When next visited, April 29, it was found to have been torn down by a windstorm, and was replaced. On May 2, 13, and 24, counts were made, the total numbers found on the respective dates being 48, 140, and 21. On July 24, two months after the last of these dates, another inspection was made; only a single borer was found on the screen. The counts made on this screen, for the season of 1916, are given in greater detail in Table 2. The maximum temperatures, read at Forest Grove, approximately 2½ miles southwest of the screen, on April 24, May 1,

May 2, and May 16, respectively, were 68°, 70°, 82°, and 77° F., each being the maximum attained since the preceding examination.

The same screen, except for a reduction in width to 18 inches, was again erected on May 1, 1917, at the western edge of a recently plowed clover field in the same location as in the previous season. Counts of borers were made from May 2, when none were found, to June 12, this date included, at intervals of from 2 to 12 days; and finally, after a further interval of 15 days, on June 27. Table 3 presents these counts in detail, in the same manner as the counts are presented in Table 2. Maximum temperatures and their dates of reading at Forest Grove were as follows, each being the maximum attained since the last previous reading: May 1, 61°; May 2, 67°; May 8, 74°; May 10, 65°; May 14, 64°; May 23, 65°; May 28, 75°; May 31, 72°; June 6 and 7, 76° F.

Of the 214 borers caught on the screens in 1916, 140, or about 65 per cent, were counted on May 12, 11 days after the last previous count. A majority of the separate counts of that date, for the opposite sides and the several sections of the screen, were more than half the corresponding totals for the season. These were probably caught on the afternoon of May 2, after the examination of the screen in the morning of that date, and on May 3, 4, and 12, when the maximum temperatures were 82°, 74°, 73°, and 67° F., respectively. The temperature did not rise above 60° F. on the other days.

Similarly, as shown in Table 3, on May 29, 1917, a date 16 days later than that of the maximum count for 1916, the total count of borers on the screen was 358, or approximately 79 per cent of the total for the season. The borers counted at that time were caught in the five days from May 24 to May 29, the maximum temperatures for each date being 60°, 57°, 64°, 71°, 75°, and 75° F., including the maxima of May 24 and May 29. Nearly every one of the separate counts for that date was a large majority, two-thirds or more, of the corresponding totals. It will be observed that the screen caught in 1917 more than four times the number of borers caught by it in 1916, and in a shorter interval of time. This may be accounted for on the theory that the borers left the plowed clover east of this screen in great numbers on the warm days of May 27, 28, and 29, 1917, after a preceding interval of cool weather. In flying most of them flew against the prevailing westerly winds. The fact that the screen in 1916 was east of plowed clover and the prevailing winds are westerly at this time may account for the fact that fewer borers were caught in that year.

As to the heights to which borers fly, it is plain that numbers of them fly 40 or 50 feet above the surface of the ground. Of those caught on the 50-foot screen in 1916, approximately 13 per cent flew more than 40 feet, 19 per cent more than 30 feet, 31 per cent more than 20 feet, and 69 per cent more than 10 feet above the ground. The corresponding percentages for 1917 were 8, 18, 37, and 61; and for both seasons combined, 9, 18, 36, and 64.

Near Forest Grove, in the season of 1917, an experiment with the small bannerlike screens, 18 by 36 inches, placed one each on the north and west sides of a field of spring-plowed clover gave interesting data as to the numbers of root borers flying from this field on

certain days. As many as 497 beetles were counted on the east side of the west screen on May 31. These were caught in the period from May 24 to the date of examination. The maximum temperatures, at Forest Grove, 2 miles west, were 60°, 57°, 64°, 71°, 75°, 75°, and 68° F., on the days preceding the count. In the same season the screen illustrated in Figure 8 was erected in the sagebrush near Wapato, Wash. This screen was located at least 1¼ miles west of land under irrigation and 2 miles from the nearest clover field. On May 22 one root borer was found on this screen, indicating that this beetle had flown as far as 2 miles from the nearest clover, which was probably the only possible source from which it could have come.

The experiments with flight screens therefore indicate that root borers may fly as high as 50 feet and possibly as far as 2 miles. The large numbers caught on small screens indicate the tremendous numbers of beetles flying simultaneously on favorable days, especially from clover fields which have been plowed in the spring. A study of these flight data leads to the conclusion that the grower can, singlehanded, do little to control this pest. Only by community action can control be attained.

EGG BURROWS

Shortly after the first spring flight, root borer adults are found in short new burrows in the roots of clover of the preceding year's seeding or in new mines on older roots. Burrows containing early eggs and females are found in the latter part of April and commonly in the month of May. Often two adults, male and female, are found in one egg gallery, so that it is evident that the males have lost no time in following the females to new host plants. Rarely two females are found together in one egg gallery, and in such cases the usual number of eggs in this common burrow is doubled. Unattached males are found feeding in superficial grooves and burrows on the clover crowns.

Toward the end of May or the beginning of June egg galleries, containing usually four to six eggs, are found abandoned by the adult borers. The earliest laid eggs at this time are found hatching minute, first-stage larvæ. New and apparently recently started mines are then found in considerable numbers on clover roots, and it seems safe to assume that in some cases the parent borers have changed roots or at least burrows. This assumption is strengthened by the observation that a single female in a cage placed over several clover plants formed egg mines in and infested more than one root. Sometimes four out of five roots in the cage were thus infested. Indications have been noted that possibly one or two other changes are made by some borers in the field. New burrows have been found in the last week of June and about the middle of July. Some of these, however, may be attributed to belated adults which overwintered as larvæ.

Egg galleries made in June and July are shorter than those of May, and the eggs are usually more numerous and closer together than in the earlier egg burrows. True pairs of adults are often found in these mines—in 1916 even as late as July 22. Adults, however, become fewer and fewer as the season progresses, so that by July old beetles are rarely found. Dead adults seldom are found in egg gal-

leries, but more commonly in superficial burrows in the crowns. It seems probable that many die outside the host plants when their reproductive life is ended, as the dead parent adults are rarely recovered in cages over growing plants.

The maximum number of eggs are found toward the end of May or the first week of June. Eggs become less common by June 30, uncommon in July, rare in August, and very rare in September. Davis (*9, p. 45*) reported that L. Whitney Watkins found an egg in a clover root at Manchester, Mich., on September 18, 1893. The writer found one egg (which hatched the next day) on September 27, 1918, at Forest Grove, Oreg.

LARVAL AND PUPAL DEVELOPMENT

The first newly hatched larvæ are recorded in the field in late May or early June. By the first of July many well-grown larvæ are present but they occur in greatest number after July 15.

The earliest recorded observations of pupæ were made in the field at Wooster, Ohio, on July 6, 1896 (*46*), and at Forest Grove, Oreg., on July 10, 1918. Pupæ do not usually occur in western Oregon until after July 15. As observed there they have not been numerous until about the middle of August, and never so numerous as other stages occurring at the same time, probably because of the brief period of this stage and the great diversity in the age and development of the larvæ. Larvæ remain in the majority until after August 15, when new adults rapidly become more numerous than the other stages. The first callow adults occur about a week after the first pupæ are observed. Occasional pupæ and newly transformed adults are observed as late as October, and more rarely in November. Soil temperatures usually are too low for development after November 15, and only larvæ and adults are observed then. A condensed summary of the seasonal history of the insect is given in Table 4, in which are listed the places and dates of observations of various life phenomena.

TABLE 4.—*Tabular summary of seasonal history of the clover root borer*

First flight of beetles	Maximum flight	Last beetles in flight	First eggs
Forest Grove, Oreg.: Apr. 16, 1915. Apr. 7, 1916. May 8, 1917. Apr. 19, 1918. Apr. 22, 1919. Apr. 26, 1920. Apr. 8, 1921. Wapato, Wash.: May 5, 1917. Hagerstown, Md.: Apr. 27, 1915 (?) Apr. 19, 1916 (?) Wooster, Ohio: Apr. 26, 1899. Lansing, Mich.: May 3, 1893. Murray, Utah: May 18, 1912.	Forest Grove, Oreg.: May 2, 1916. May 28, 1917. Wapato, Wash.: May 10, 1917.	Yamhill, Oreg.: July 14, 1915. Forest Grove, Oreg.: July 11, 1916. Silverton, Oreg.: July 13, 1917. Wapato, Wash.: June 18, 1917.	Forest Grove, Oreg.: Apr. 21, 1915. Apr. 22, 1916. Apr. 29, 1918. Apr. 27, 1921. Hagerstown, Md.: May 18, 1916. Wooster, Ohio: May 17, 1898. May 17, 1899. Michigan: June 4, 1893. May 20, 1894.

TABLE 4.—*Tabular summary of seasonal history of the clover root borer*—Contd.

Last eggs	First larvæ	Maximum larvæ	Larvæ less than 50 per cent
Albany, Oreg.: Aug. 9, 1915.	Forest Grove, Oreg.: May 15, 1915.	Forest Grove, Oreg.: July 19, 1915.	Forest Grove, Oreg.: Aug. 26, 1915.
Forest Grove, Oreg.: July 22, 1916. Sept. 19, 1917. Sept. 27, 1918.	May 17, 1916 (cage). June 8, 1917 (cage). June 3, 1919.	July 18, 1916. July 25, 1917.	Aug. 28, 1916. Aug. 22, 1917. Aug. 24, 1918.
Hagerstown, Md.: Aug. 23, 1916	Hagerstown, Md.: May 24, 1916 (cage). June 8, 1916.	Hagerstown, Md. July 22, 1915 (?) July 27, 1916 (?)	Hagerstown, Md.: Aug. 25, 1916.
Manchester, Mich.: Sept. 18, 1893.	Murray, Utah: June 20, 1912.	Murray, Utah: Aug. 12, 1911 (?)	
	Wooster, Ohio: June 8, 1898.	Wooster, Ohio: July 12, 1898 (?) July 17, 1899 (?)	

First pupæ	Maximum pupæ	First adults
Forest Grove, Oreg.: July 19, 1915. July 30, 1916. July 26, 1917. July 10, 1918.	Forest Grove, Oreg.: Aug. 27, 1915. Aug. 23, 1916. Aug. 22, 1917.	Forest Grove, Oreg.: July 27, 1915. Aug. 15, 1917. Aug. 2, 1918.
Hagerstown, Md. July 22, 1915. July 21, 1916.	Wapato, Wash.: Aug. 12, 1915.	Yamhill, Oreg.: July 24, 1916.
Wooster, Ohio: July 6, 1896. July 19, 1898. July 7, 1899.	Hagerstown, Md.: Aug. 15, 1916.	Hagerstown, Md.: July 26, 1915. July 21, 1916.
		Wooster, Ohio.: July 6, 1896. July 17, 1899.

FALL ACTIVITY

In about four days from the time of emergence from the pupal stage, the new adults become sufficiently matured to begin feeding, and they continue to feed, by enlarging the larval burrows in the roots in which they matured, until low soil temperatures limit their activity. The adults, with few exceptions, pass the winter in the roots in which they have undergone complete development. In the event of the death and desiccation of the root in summer or early fall, the adults gnaw their way out and seek living roots in which to feed and hibernate. Such forced migration may be by flight, as two root borers were taken on flight screens at Forest Grove between September 18 and October 7, 1918. Larvæ and adults may survive until spring on dead roots, provided these do not become too dry. In fact, dead, punky clover roots containing many old larval galleries are the most successful wintering quarters for the adults. Larvæ probably hibernate most successfully on roots in which there is some life.

LIFE HISTORY

OVIPOSITION

After the first mating the fertilized female burrows into a clover root of the preceding year's seeding, or a still older root. These burrows usually start on the clover crown but occasionally begin on the side of the root an inch or two below the crown. The egg galleries vary considerably in character of construction and in length. Some are simply grooves, some pass from grooves to completely inclosed galleries, some are completely inclosed galleries from the

first. They may run parallel with the longitudinal axis of the root or at right angles to it or occasionally there is a combination of both. Maternal galleries are sometimes spiral grooves almost girdling small roots. Occasionally, especially in the case of a root crowded with borers, the egg gallery runs into the center of the stem above ground and eggs are laid in the pith.

A root borer was observed starting its burrow on an exposed root in the laboratory. When first noticed it had dug in up to its mesothoracic legs, these being used to maintain a grip on the rim of the hole, while the hind legs were often waving in the air. The body was occasionally rotated in a complete circle, the head not being withdrawn from the hole.[9] Evacuation of feces took place during the observation, and as there was only a small quantity of whitish sawdust outside the entrance, the indications were that the borer ate most of the material taken from the burrow. In about 24 hours this borer was completely within the gallery, having progressed approximately 3 mm. since the observation of the previous day. In another instance the borer advanced at about the same rate, or approximately 6 mm. in two days.

The females burrow to a depth of at least 6 mm. before starting oviposition. Oviposition was not observed, but probably proceeds as described for other scolytids; the female backs out of the gallery and then backs in to deposit her egg in a niche in the wall of the gallery which she had previously prepared for its reception (*4, p. 34; 15, p. 17*). After the egg is laid in its niche, the opening into the egg gallery is securely plugged with frass cemented together with a sticky material, probably secreted by the female beetle (*4, p. 34*). These egg pockets usually are 2 to 6 mm. apart, but sometimes are almost contiguous. Those in longitudinal mines are in the side toward the core of the root; those in a horizontal mine are usually on the upper and lower sides alternately. Those in completely inclosed galleries are often on alternate sides of the gallery. The egg galleries formed in May measure from 20 to 30 mm. in length, have four to six well-separated egg pockets, and are usually longer than those found later, in June and July. These later galleries, probably the second or later effort of the females, measure from 15 to 20 mm. long and usually their egg pockets are very close together and more numerous than in the May galleries. Sometimes as many as nine eggs are found in one short gallery. Rarely two females are found together in one egg gallery, which is longer and contains more eggs than in the case of a single female; in one such case the gallery contained two females and 12 eggs.

The construction of the egg gallery and oviposition in it are together a rather slow process. In the laboratory, under conditions of higher temperature than would prevail in the soil in the field, one female extended her mine 13 mm. and laid four eggs in 14 days. It is therefore probable that the construction of the first egg gallery occupies the female for nearly a month. This assumption is corroborated by field observations, which indicate that the second egg galleries are started about the end of May and during the first part of June.

[9] See Blackman (*4*) for a good description, with figures, of a scolytid starting an egg gallery.

Males accompanying females in the egg galleries are common during the whole period of reproduction, and it is believed that the female is fertilized more than once during her reproductive period.

Only one case has been observed where eggs were laid in the walls of what appeared to be a hibernation chamber or last year's larval mine. This, a case of three eggs (two in one pocket), in pockets leading from an old central boring, was recorded at Yamhill, Oreg., May 13, 1915.

INCUBATION PERIOD

The incubation period of the eggs is apparently dependent on the temperature to which they are exposed. In determining the length of this period under northwestern conditions the writer found that his records varied to an unusual extent from those of workers in other parts of the country, as well as from those of earlier authors, both American and European. Schmitt (*39, p. 394*) stated "Schon nach 8 Tagen findet man die kleinen Lärvchen." The American authors, Riley (*37*), Webster (*45, 46, 47, 48*), and Davis (*9*) apparently accepted Schmitt's egg period, as their papers on this insect contain no intimation that they attempted to ascertain the incubation period. H. L. Parker made several incubation experiments at Hagerstown, Md., placing root-borer eggs on moist blotting paper in tin salve boxes, the location of which during the incubation is not stated. The egg period under these conditions was 10 or 11 days; "eggs from burrow," May 18 to May 29; "deposited since yesterday," May 19 to May 29; and "eggs of June 8," June 8 to June 18, 1916. He recorded a large percentage of eggs as dead in from 12 to 17 days.

Incubation chambers identical, or nearly so, with those used by Parker were used in the writer's experiments, carried on at Forest Grove. Most of the salve boxes contained plaster of Paris cells, which were moistened as needed. In a few cases the eggs were left in position on a piece of clover root which was then placed on a moist blotter or in a plaster cell in a tin salve box. All of the writer's records given here refer to these types of incubation apparatus, which were placed outdoors, in the shade on the north side of a building, beside a thermograph, or on a bench in a screened insectary. The eggs used were of unknown age, dissected from roots collected in the field. With a little experience in observing such eggs, it was easy to distinguish between a fresh or recently laid egg and one laid several days previously. The records secured for eggs collected in the field soon after oviposition began may be considered approximately correct for the egg period at that season. Later records, when the freshness of eggs could not be assumed *a priori* but was necessarily estimated from their appearance, would be less reliable. On the other hand, of the same lot, the eggs taking longest to hatch under exactly identical conditions as compared with others hatching earlier are assumed to have been the freshest of the lot when the experiment was started. These records are given in Table 5, together with the mean temperatures during the period and a summation of the effective temperatures as estimated according to Pierce (*35*) and Sanderson and Peairs (*38*). The estimated zero of effective temperature is 45° F., and the approximate temperature constant is 300.

TABLE 5.—*Results of experiments on incubation of eggs of the clover root borer, conducted at Forest Grove, Oreg., in 1916, 1918, and 1919*

Number of eggs	Date of beginning of incubation	Date of hatching	Mean temperature	Time of incubation	Number of days above 45° F.	Effective temperature	Accumulated temperature
	1916	1916	°F.	Days		°F.	°F.
2	May 3	June 6	53.8	35	32	8.8	281.6
2	1	2	53.9	33	30	8.9	267.0
[12][1]	12	10	54.5	30	30	9.5	285.0
[12]	12	11	54.8	31	31	9.8	303.8
[5]	19	13(2)[2]	55.6	26	26	10.6	275.6
[5]	19	14	56.1	27	27	11.1	299.7
15	25	14(1)	57.4	21	21	12.4	260.4
24	29	15(4)	59.2	18	18	14.2	255.6
18	June 20	July 8(3)	59.3	19	19	14.3	271.7
26	15	2	60.7	18	18	15.7	282.6
2	26	11	60.9	16	16	15.9	254.4
1	23	11	61.0	19	19	16.0	304.0
[51]	2	19	61.9	18	18	16.9	304.2
[51]	2	18	°62.3	17	17	17.3	294.1
25	9	24(2)	62.3	16	16	17.3	276.8
	1918	1918					
Uncounted	May 21	June 10	59.4	21	21	14.4	302.4
	1919	1919					
Do	June 3	June 24	58.8	22	22	13.8	303.6
Do	3	25	58.9	23	23	13.9	319.7

[1] Bracketed items in the first column refer to the same lot of eggs.
[2] Figures in parentheses in third column indicate the number of eggs found hatched on the date named.

It appears from these records that the incubation period in the Pacific Northwest is very much longer than Schmitt (*39, p. 394*) noted for Germany, or than Parker recorded for Hagerstown. The records also show that this period is longest in May and considerably shorter in June. As incubation occurred in what may be assumed to have been an atmosphere of uniformly high humidity, temperature is probably the determining factor causing the difference in incubation period. It is possible that there are sufficient differences in the mean daily temperatures at this season in different localities to account for some of the recorded differences in the incubation period.

The incubation period of about 30 days in April and May as determined by laboratory methods is shown by field observations to be approximately correct for the Willamette Valley, and seems more nearly to correspond with the seasonal history as recorded in the field at other places. It is concluded from experimental evidence that the incubation period in clover roots at effective temperatures varies from 32 days in May and early in June to 16 days in June in western Oregon, and, judging provisionally from observations made elsewhere, is perhaps as short as 10 days in some localities where soil temperatures average considerably higher.

LARVÆ AND LARVAL MINES

Newly hatched clover root borer larvæ were found to be helpless, inactive creatures incapable of locomotion on a smooth surface. The leverage made possible by the small egg cell, with its opening into the egg gallery securely plugged, seemed absolutely necessary for the successful attack of the larvæ on the clover roots. The young larva

excavates a fine threadlike mine, usually at right angles to the egg gallery, for from 3 to 5 mm. At this point the larva molts for the first time and starts off again at right angles to the first part of the burrow, but usually parallel to the longitudinal axis of the root. The first several millimeters of the young larva's burrow are eaten out very cleanly, leaving as a residue only a blackish excrementitious material. As the larva increases in size its burrow often becomes sinuous, but conforms in a general way to the longitudinal axis of the root. Frequently its later extensions are nearly straight, and at this stage the tunnel often runs down the center of the root. This latter part of the burrow is closely packed with a bright brown frass in which the broken remains of the molted head capsules are found at intervals. An extensive study of such burrows indicated that these head capsules occurred approximately as follows: The first at 3 to 5 mm. from the egg niche; the second at 5 to 8 mm. from the first; the third at 7 to 10 mm. from the second; the fourth at 10 mm. from the third, or, in case of apparently only four molts, at 15 to 16 mm. from the third; the fifth at 6 to 8 mm. from the fourth.

Larval mines vary much in length, the shortest being nearly 20 mm., the longest 35 to 40 mm. long. The clean, smooth sided pupal chamber occurs at the end of the mine, usually well down in the root, but sometimes on or near the crown. The pupa usually lies with its head toward the surface of the soil; this was believed to be invariable and is so stated by Schmitt (*39, p. 395*). However, a few pupæ lying head downward were found September 24, 1921, on clover roots. It is possible that the position of the pupa is reversed soon after pupation.

The actual number of larval molts is very difficult to determine, because of the difficulties met in rearing the larvæ under observation and because of the fragile nature of the lightly chitinized molted head capsules left in the larval burrows. Another difficulty encountered was that of tracing individual burrows in heavily infested clover roots, as burrows often crossed and frequently ran together, so that two larvæ were sometimes found at different parts of one burrow. Evidence secured from the examination of many larval burrows indicates that there may occur a variable number of molts, four or five, or perhaps occasionally only three. There was also so great a variation in the size of the larvæ at all stages, except perhaps the first, that it was not possible from larval measurements to assign a given larva to any instar. The measurements of the larval head capsules, as the most chitinized parts, were used for comparison. In some cases measurements immediately following the molt showed very little increase in the size of the head capsule. This fact was occasionally noted by H. L. Parker, at Hagerstown. Head capsules varied in the relative proportions of their length to their width, and it seems possible that this variation may be partly sexual, as the male adult head is relatively narrower than the head of the adult female.

The larval head capsules cast at the first molt measured as follows: Length (without mandibles), 0.30 to 0.35 mm.; pleurostoma, 0.07 mm.; width of front, 0.13 mm.; epistoma, 0.13 mm. The last molted heads taken from the pupal chambers measured as follows: In length (without mandibles), 0.55 to 0.70 mm.; pleurostoma, 0.13 to 0.14 mm.; width of front, 0.32 to 0.36 mm.; epistoma, 0.23 to 0.26 mm.

LARVAL PERIOD

The larval period varies with the conditions under which the larvæ develop, both temperature and the condition of the host root being factors of importance. The shortest larval period, passed in a bare piece of clover root, contained in a tin salve box on an insectary bench, was estimated at 32 days, that is, 42 days hatching to callow adult, less 10 days pupal period, June 13 to July 25, 1917. Other individuals under similar conditions had larval periods of 39 to 65 days. When the newly hatched larvæ were placed in artificial pockets formed with a needle in young living clover roots, the openings plugged, and the plants grown in the insectary, the following larval periods were recorded in June, July, and August, 1919: 55 days minus (fresh pupa), 52 days plus (prepupal larva), 46 days plus (well-grown larva), 62 days minus (fresh pupa). These results indicate a larval period of at least 50 days under nearly natural conditions for development. Seasonal field records indicate a minimum larval period of about this length, or nearer 60 days for the Willamette Valley, more than 40 days for Hagerstown Md., in 1916, according to notes made by H. L. Parker and W. E. Pennington, and about 40 days for Wooster, Ohio, in 1898, according to notes made by Webster and C. W. Mally. Later in the season, when temperatures are lower, in cold or shaded soil, on large, healthy roots little affected by borer attack, field records show that the larval period is prolonged. Such records indicate that borers develop more rapidly on dying roots than on healthy roots. Observations in a field containing many dying and dead plants indicated that most of the root borers attained the adult stage by the middle of September, at the same time that roots in neighboring fields where most of the plants were still living contained many larvæ and pupæ.

PUPAL PERIOD

The pupal period was determined by placing naked pupæ, whose date of entering pupation was known, on a piece of moist blotter or moistened plaster of Paris in a tin salve box kept on a bench in a screened insectary. The pupal period was determined as 10 days, from August 17 to August 27, 1917. In September and early October the pupal period was often 12 to 13 days. Webster and Mally recorded a pupal period of 7 to 11 days on moist sand at Wooster, July 6 to July 13, 15, and 17, 1896, observing pupæ of unknown date taken from roots. H. L. Parker noted a pupal period of 7 or 8 days in the early part of August, 1916, at Hagerstown, Md.

Adults fresh from the pupal stage are of a pale creamy white color, and several days elapse before they become sufficiently chitinized to feed on the clover roots.

By reviewing the life history of this species, it may be observed that its development is a very extended process. Field and laboratory records indicate a total period from fresh-laid egg to adult of 60 or more days at Hagerstown, Md., and Wooster, Ohio, and at least 70 days, or even as much as 90 days or more, in the Willamette Valley in Oregon. The life history and seasonal occurrence of the clover root borer are illustrated graphically in Figure 11.

SEXUAL DEVELOPMENT

In order to obtain information as to the time of sexual maturity, rate of reproduction, and number of generations annually, studies of the genital organs (fig. 12) of the root borers were undertaken at different seasons.

Examinations of females in the fall seem to prove conclusively that there is but one generation in a season. Records of fall examinations are as follows: September 7, 1915, 10 females showed no egg development; 6 males had testes well developed. October 7, 1915, 2 males and 1 female were collected from new burrows in clover crowns in a field, a strip of which had been plowed in the summer; no eggs were found developing in the ovaries of the female. On the same date 38 males and 27 females were taken, mainly from dead roots; 4 of the females had first traces of egg formation (in one case estimated to be one-eighth grown); no others had any indication of incipient egg formation. October 7, 1918 (a warm, dry season), 3 female adults were taken from a plant collected and transplanted August 26. All of these were contained in burrows in live root tissue; only 1 female had any egg development; in this case 3 very immature eggs were contained in the ovarian tubes. October 2, 1918, of 6 females

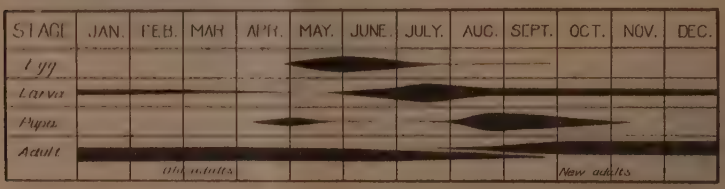

FIG. 11.—Diagram illustrating life history and seasonal occurrence of the clover root borer

taken from living roots, 3 contained no eggs, 1 contained two incipient eggs appearing as dusky spots, and 2 contained eggs barely visible in the ovaries. Of 31 male and 30 female borers collected October 7, 1918, in dead roots, and examined October 10, only 1 female had any trace of egg development, there being two very small developing eggs in the ovarian tubes. Three females were taken October 14, 1916, from roots in a cage, all of which were reared from a female introduced into the cage March 9 (almost a month before the first spring flight); none of these daughters were found to have any eggs developing in the ovarian tubes. Another female reared under the same conditions was found with an incipient egg.

Males evidently are mature in the fall, as they have been observed to mate or attempt mating when brought with females into the laboratory by the writer and by H. L. Parker, at Hagerstown, October 16, 1916, and October 6, 1915, respectively. Folsom (*12*) reported a pair, taken from roots in the field, in copulation in a cage in the laboratory on September 9. On October 3 he found on this plant larvæ, but no eggs, and one of the adults (sex not stated) died before November 21. The female in this case may have been a belated adult of the previous generation.

Examinations of the sexual organs of borers during the latter part of February, 1916, revealed but 2 females showing egg formation; of

these one contained an egg about one-fourth grown; the other, two immature eggs about one-eighth grown. Fifteen females, taken from roots in the field March 23, 1920, were almost without signs of egg development in the ovarian tubes. The single exception showed traces of first egg formation. Both sexes of the latter date had been feeding and evinced some development of the fat bodies. On March 28, 1916, of 6 females from roots collected in the field March 15 and stored in a root cellar, none contained eggs, but 3 had been recently fertilized, as they contained balls of sperm in the accessory sacs. In one case, May 6, 1915, a female from a hibernation chamber in an old root had no egg development.

Incipient egg formation, with rarely an egg as much as one-half grown, more frequently with eggs one-fourth grown, was usually found in females collected in flight. This state of the ovaries was the same in females swept late in the season of flight, according to records for June 3, 1916, and June 4, 1915.

A careful examination of 14 females collected in flight April 26, 1920, corroborates the former statement and, in addition, shows that only one of the 14 females was unmated. All the others had mated previous to capture in flight, most of them so recently that the accessory sac was distended with sperm and in at least one case so recently that no spermatozoa had yet reached the spermatheca, although the accessory sac was much swollen with sperm.

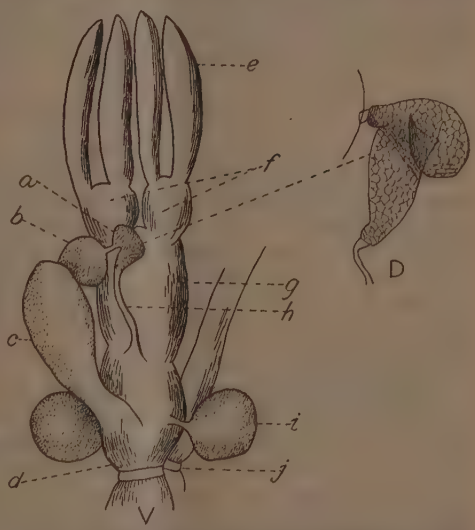

FIG. 12.—Diagrammatic drawing of sexual organs of the female. *V*, ventral side; *a*, sperm theca; *b*, spermathecal gland; *c*, accessory sac; *d*, vagina; *e*, ovarian tubes; *f*, paired oviducts; *g*, unpaired oviduct; *h*, seminal duct; *i*, cement glands; *j*, anus. *D*, Spermatheca further enlarged. Redrawn from Rockwood. Greatly enlarged

Examinations of the female genital organs during the oviposition period brought out the fact that eggs mature and are laid very slowly. Such examinations indicate that the ratio of developing eggs is approximately 1: ½: ¼: ⅛, etc. Examinations of females in egg galleries indicate a considerable interval of time between the maturation of the eggs, except in the rare case of simultaneous development in two ovarian tubes. The interval is apparently occupied by the female in feeding, prolonging the egg gallery, and forming the cell for the reception of the egg. Observations and dissections of females in egg galleries have also indicated that there is a considerably longer interval between maturation of individual eggs at the time an egg gallery is completed. In one case a female, which was in a mine with five eggs, had no other eggs in her ovarian tubes more than one-eighth grown. It seems likely that such interruptions

of development may occur periodically, perhaps between matings, and thus afford the female the few days necessary for preparing a new egg gallery. Such females swept late in the season in flight would have a sexual development similar to that of those on their first flight. It is a doubtful point, therefore, whether the individual makes more than one flight.

Examinations of individuals of both sexes of the parent generation indicate that some were reproducing as late as July 18, 1916, and August 13, 1920. On the latter date one male had testes still functioning and one female had been recently mated. Two females had living spermatozoa in the spermatheca, but no sperm in the accessory sac. In a cage experiment started with a male and a female March 20, 1918, the female was still alive July 25 and her ovaries were developing eggs, although visibly near depletion. It was found from a record made at Forest Grove that a male introduced into a cage April 24, 1917, still survived September 27, neither the female of the pair nor any offspring being recovered.

NUMBER OF GENERATIONS

There has been considerable difference of opinion as to the number of generations produced annually by this species. American authors are unanimous in their conclusion that there is but one generation a year. Most European authors, with the exception of Schmitt (*39*), have maintained that this species has two or more generations. Del Guercio (*16, p. 271*), the latest European writer to treat of the species, seems to conclude that there are three generations per year on *Trifolium pratense* in Tuscany, although his seasonal notes agree closely with those recorded above for Oregon, western Maryland, and Ohio.

American workers, notably Riley (*37*), Webster (*46*), and Davis (*9*), who have studied the species carefully, have noted that there are no well-defined periods in the seasonal development. The studies of the writer, the results of which are here given under the heads of sexual development, seasonal history, and life history, seem to afford the explanation of this fact. Records of other workers have afforded confirmatory evidence.

All the evidence based on the facts observed in the development of the clover root borer tends to show that there is but one generation in a year, or even that a single generation overlaps the year. The female already noted, which had in all probability matured the previous August or September, was alive in a breeding cage and reproducing on July 25 following. There is also the case of the male previously mentioned which survived in a cage from April 24 to September 27. It is safe to assume that one of these individuals passed an adult life of almost a year. The male may have been produced in April from an overwintered larva, but even in that case it must have belonged to the parent generation, the offspring of the previous season. Adults of the parent generation have also been recorded as alive and reproducing as late as August 13.

Eggs of the clover root borer have been found in clover roots in the field as late as August, and once on September 27. In the latter case the egg hatched the next day and must have been at least

20 days old. It is possible that oviposition in this case may have been done by a precocious individual of the new generation, but no evidence appears to indicate that such early sexual development takes place; whereas there is evidence that an adult, the mature form of an overwintered larva, might lay an egg on that date. As adults produced at the normal time (August or September) are known to have an active reproductive period of at least three months, in addition to the active feeding period of several months in fall and early spring (making an adult life of about 10 months, of which perhaps 5 are active), adults produced in May from overwintered larvæ would almost certainly, barring accidents, be alive and reproducing about the beginning of September. As the period of development from new-laid egg to adult is about two and a half months in spring and summer, larvæ hatched from eggs laid in the late summer and fall are not able to complete their development before winter causes a cessation of activity. Some of the offspring of these belated individuals tend to be belated also. This is a plausible explanation of the frequent occurrence of hibernating larvæ, and rather conclusive evidence that there is but one generation a year on red clover in America. Evidence in support of this theory is afforded by Parker's notes at Hagerstown, Md. Parker took adults from clover roots on August 25, 1916, and placed them on clover roots in tin boxes. These individuals had laid no eggs by September 29. In another case he confined early adults of the new generation on clover all summer, but obtained no eggs in the fall.

RATE OF REPRODUCTION

As already noted, the female beetles mature eggs slowly, and but few eggs are laid in the first egg galleries during a period of three to four weeks in May, when the soil temperatures range low. There is evidence that the female changes her egg gallery two or three times during the reproductive period, thus occasioning delay or diminution of egg production.

Experiments to determine the total progeny of one pair of borers were conducted at Forest Grove, Oreg., using cages of three types: (1) Flower-pot cages containing one or two clover plants and covered with a lantern globe; (2) cylindrical wire-mesh cages buried in the ground, planted with one, two, or three clover plants, and covered with a lantern globe; and (3) wire-screen cages 3 by 3 by 3 feet in size, lined with cheesecloth and placed directly over five young transplanted clover plants growing in the soil. Clover plants were collected from fields sown the previous spring, gathered before March 15, and apparently free from infestation. Cages were started before the first flight of borers, except in 1920, when the experiments began coincident with the first flight. Each cage contained a single pair of borers.

The flower-pot cages dried out very rapidly in midsummer, undoubtedly thereby shortening the life of the adults. The borers were also too closely restricted, a pair having but one or two roots to work on. The total progeny of one pair recovered from each of six cages of this type in one season was 6, 6, 3, 8, 8, and 26, respectively.

The wire-mesh cages sunk in the ground more nearly approached natural conditions, but the borers were again in some cases restricted

to too few roots. The total progeny of one pair in each case recovered from 12 cages of this type was, in cages containing one root, 13, 14, 9, 16, and 9, in the season of 1917; in those containing two roots, 13, 16, and 15 in the same season; in those containing three roots, 4, 21, 14, and 21, in the season of 1918. For all cages of this type the average progeny of a single pair is 13.75.

The square screen cages placed on the ground over five clover plants furnished practically optimum conditions for reproduction. Unfortunately, however, these cages allowed access to other borers from below, in case any had wintered over on the spot of ground selected for a cage. As it was discovered that a control cage supposedly kept free from root borers contained infested roots, some of the records for this type of cage were disregarded. However, one cage of this type was examined early enough (July 25, 1918), to be certain that only the one female had had access to the roots. In this case a pair of borers in copulation had been introduced into a cage on March 20; when the cage was examined July 25, 19 larvæ in all stages, 2 pupæ, and the living female parent were recovered on four of the five roots. The beetle, when dissected, contained 1 half grown and 3 immature eggs in shrunken, depleted ovaries. She therefore showed an actual progeny of 21, or an estimated possible progeny of 25. In 1920 particular care was taken to bar out of the cages all root borers other than those intentionally introduced. In one of these experiments a cage which contained a verified pair of borers, placed in it May 3, contained, when examined August 11, 1 pupa and 4 larvæ on one root, or a total progeny of 8. Another true pair, placed in another cage May 6, yielded 4 pupæ and 5 larvæ on August 11, or a total progeny of 9. Three similar attempts with single females swept in flight failed to produce young.

From a survey of the conditions attending these experiments, it is believed that the most reliable information as to the rate of reproduction results from the use of the cylindrical wire mesh cages containing three clover plants, in soil known to be free from infestation. In each of two cases in 1918 the maximum progeny thus obtained was 21. A reliable result is also thought to have been reached with the cubical wire-screen cage examined before the death of the parent female, in which were found actual progeny numbering 21, or estimated possible progeny of 25. In all experiments the borers were protected from natural enemies and were on clover plants in partially shaded ground, the cages being covered with cheesecloth. These conditions were believed to be more favorable to root borer activities than would be the case in plants in soil under natural conditions. It is therefore deduced that the total progeny of one female in nature rarely exceeds 25 in number, and probably averages considerably fewer than that.

It may therefore be concluded from the foregoing data on the reproductive activities, life history, and seasonal history of this insect that it is a slow and by no means prolific breeder, and that if some of the existing agronomic practices, together with its protected mode of life, were not favorable to its undisturbed increase, it would not be a widespread, destructive pest.

ECOLOGY

TEMPERATURE

Many of the data that have been given indicate that the activities of this insect are greatly influenced by temperature. This factor controls the activities and migration of the borers in the spring. At this time migration from old to new clover fields is determined by the temperatures of the soil and air. The dates on which these migrations occur vary not only from one season to another but also from field to field, as borers leave clover roots in cold, wet, poorly drained spots several days or even weeks later than flights of borers from clover on warmer soil. Soil temperatures during the period of development determine the time consumed in the completion of that development. Field observations indicate that on clover in shaded places, such as orchards, where the soil temperatures doubtless are lower than in the open fields, the development of root borers is so much delayed that an unusual number of overwintered larvæ are found in such places in the spring. Unpublished notes made by E. J. Vosler at Murray, Utah, in 1912, record an unusually large number of overwintered larvæ, and indicate that the period of development is affected by low soil temperatures, owing to the short season at high altitudes, or perhaps to the cooling effects of soil moistened by irrigation. The comparatively low temperatures of the heavy clay-loam soils near Forest Grove, Oreg., in the spring and early summer appear to prolong the development of the insect to an appreciable extent as compared with the conditions in the spring and early summer in Ohio and western Maryland.

MOISTURE

Moisture is also an important factor in the life of the species, both directly and in its secondary effects on soil temperature (*26, p. 220*) and the condition of the host plant. Clover root borers in any stage are very susceptible to injury by dryness; even the well-matured adults survive but two or three days in a dry vial. All stages, even adults, if they are unable to escape, are killed by the rapid drying of the host roots. If the roots dry slowly, as in the case of undisturbed roots dying in early summer, adults that are sufficiently hardened to gnaw their way out hasten to escape and find moist living roots. A lack of moisture in the soil affects the root borers indirectly through its effect on the host plant and the soil temperature. In spite of the unfavorable effect of dryness on the species, however, it has often been noted by workers that in a dry summer the root borers are more injurious to clover. As will be shown, the borers thrive best on weakened plants, such as result from droughts; not only is the moisture insufficient for the natural growth of the plants, but the accelerated development of the borers enables them to inflict all the more damage.

CONDITION OF HOST PLANT

The condition of the host plant is of course of great importance in the life history of the insect. Although there is little evidence to support the theory advanced by Schmitt (*39*) and others that weak-

ened or dying plants are the preferred food of the clover root borer, there is evidence that development is most rapid and secure on the roots of clover plants which have received a check to their vegetative activity. This fact was also noted by Riley (37), who stated that the root borer "flourishes most in the roots of plants that have been injured and that have already begun to decay." Such a vegetative check usually occurs naturally in most clover regions in July and August, when the second crop of clover has matured its foliage and is producing seed. Summer droughts also check the vegetative growth and thereby accelerate the development of the root borers. An artificial or mechanical check to vegetative growth is produced by the simultaneous attack of several root borers, whose combined burrows seriously interfere with the functions of the root. Checks to vegetative growth may also be occasioned by disease or by the attacks of other insects and may sometimes be due to a failure of the soil to produce the elements required for continuous growth of the plant.

Hibernation has frequently been noted to be more successful on very much weakened roots or roots which have died late in the season and are more or less decayed than on roots still in a healthy condition. An indication of the disadvantage to the root borers of a healthy growing root as a place of hibernation was observed on October 4, 1917. In this case three root borers were found dead in their pupal cells and crushed out of shape. This fatality apparently was due to the partial closing up of the cells caused by the growth of the root before the adults were sufficiently hardened to enlarge the chambers.

Data showing the effect of a continuous vegetative period on the clover root borer were obtained in observations made on the bottom lands along the sloughs of Coos River and in the Coquille Valley, Oreg. Under conditions occurring there, clover grows very rapidly and probably almost continuously, because the winter temperatures are mild (42), the climate humid, and the soil rich and well supplied with moisture by a natural subirrigation as well as by considerable precipitation (42). Root borers are very scarce in this clover on the bottom lands, even in the second and third years. Yet, on the poorer hill soils in the same region, which are not naturally subirrigated, the borers are as bad on first- and second- crop-year clover as anywhere in the Willamette Valley.

TOPOGRAPHY

The distribution of the clover root borers and the damage done by them are often influenced by the topography of the region in which they occur. Low, wet, poorly drained soils, which remain cold late into the spring, retard the development of the root borers and encourage fungous diseases; but higher, warmer land may accelerate their development over much of the surrounding country.

It has been observed that small farming communities isolated from the surrounding cultivated country by woods or wooded hills are often very severely infested. Often the portion of a field along the windward side of a grove is more severely infested than the rest of the field. A case was observed where a field about one-fourth of a mile from an old field that had been plowed in spring, with open country between the two, was very severely damaged by July. On the contrary, a second field, about as near the source of infestation as the

first and in approximately the same direction from it, but with a small wooded area between, showed at the same time no serious damage. These observations may be explained by the fact that the greater number of root borers appear to fly below a height of 30 feet, and thus the wooded country encountered acts as a barrier and causes them to gather in indentations on the edges of the woods, or turns them back into the clover fields on the windward side. This assumption is borne out by accumulated flight records and records of collections of beetles taken in flight along the windward margin of woodland areas. Advantage might be taken of this barrier effect to ward off root borer injury in farming communities that are isolated by surrounding woodlands from other farming communities.

OTHER HOST PLANTS

Common red clover, *Trifolium pratense*, and mammoth clover, *T. medium*, are the preferred host plants of the clover root borer. Alsike clover is attacked and may be severely injured, especially in sections where recent changes have been made from red clover to alsike in the general cropping practice. The roots of alsike do not appear so well adapted as a nidus for the root borer as are those of red clover, probably because of their more sappy, tender texture. That alsike is not an altogether suitable host is indicated by the fact that adults which had been killed by a fungus before penetrating very far in alsike roots were commonly observed at Forest Grove in 1921.

Clover root borer adults have been observed attacking alfalfa and sweet clover plants in the Yakima Valley, Wash. They were found, two or three to a root, in superficial burrows in the crowns of these plants, which were growing in an orchard where the clover had been practically all killed by the root borers. Adults were found dead of fungous disease in such superficial burrows on sweet clover crowns. These observations were made on May 22; on a later visit, C. W. Creel was unable to find living root borers in any stage on these plants. The indications in this case were that the root borers had been forced by hunger to attack alfalfa and sweet clover roots, finding no other food in the immediate vicinity, and had not been successful in reproducing on these plants. The roots in this case were of large size. It is possible that the borers might have been more successful on younger, smaller plants, as Gibson (*13*) stated that in Ontario "In some fields of alfalfa this borer was working freely, causing noticeable loss. In one field examined 31st July, two adult beetles were found in a root which had been tunneled by the larvæ." Folsom (*12, p. 114*) also stated that the root borer feeds on alfalfa, "but not enough to have done any damage up to the present time."

Schmitt (*39, p. 392-393*) stated that he did not observe clover root borers on *Medicago sativa* and *Hedysarum onobrychis* (*Onobrychis visiaefolia*) near Mainz. Kaltenbach (*25, p. 121*) included *Medicago sativa* among the plants whose roots are attacked by this species, and Vassiliev (*43*) listed this insect as a pest of lucerne in Russia. Del Guercio (*16, p. 264*) stated that alfalfa is not known to have been attacked by it in Tuscany.

There is a large acreage of alfalfa in the Yakima Valley, Wash., in the vicinity of clover fields severely infested by root borers, but no evidence of infestation by root borers has yet been found in these

alfalfa fields. Fields of alfalfa in the Willamette Valley have frequently been examined, but no root borers have been found there on alfalfa roots, even when they were close to badly infested clover roots. At Murray, Utah, repeated examination of large numbers of alfalfa roots, even in badly infested clover fields, by T. H. Parks, E. J. Vosler, and P. H. Hertzog, resulted in the discovery August 23, 1911, by Hertzog, of but one pupa of a clover root borer on an alfalfa root. H. L. Parker tried unsuccessfully to transfer the larvæ from clover to alfalfa roots at Hagerstown, Md. It seems improbable that the clover root borer will become a serious pest of alfalfa, as the rapidly growing, tough roots of alfalfa do not appear well adapted to the successful propagation of the species.

Adult root borers were found by C. W Creel attacking a field of common vetch near Junction City, Oreg., May 24, 1918. Two out of ten roots examined were infested and some roots were almost girdled by the burrows of the adults. There were no signs of immature stages, and the vetch roots probably would not be sufficiently large to serve as a breeding place for root borers.

Root borer adults were found in burrows in the crowns of *Lupinus* sp. near Albany, Oreg., on May 29, 1919. The burrows were superficial and more in the stems than in the roots.

F. M. Webster noted an attack by clover root borers in pea vines at Wooster, Ohio, June 30, 1892. In this case the burrows were in the stems, near the ground. A. L. Lovett, of the Oregon Agricultural College, reported [10] that commercial plantings of garden peas over a limited area in Marion County, Oreg., were damaged by clover root borers to the extent of 60 per cent of the crop on June 2, 1922. Professer Lovett noted that these plantings were adjacent to fields of old, abandoned clover heavily infested by root borers.

On April 4, 1922, at Forest Grove, Max M. Recher found a plant of Scotch broom, *Cytisus scoparius*, with a stem about one inch in diameter and turning yellowish on the terminal twigs, which contained a typical bark-beetle burrow in the soft wood under the green bark. This mine was some distance up the stem, but below any branches. The gallery was two-armed, the branches extending in opposite directions from the entrance. This burrow was much discolored and must have been formed some time in the previous season, and perhaps represented a true hibernation burrow (*22, p. 203*), as there were no signs of reproductive activity. The bark beetle was accidentally mutilated with a knife, only a part of the thorax, the legs, and the head being recovered. These parts had all the characters of Hylastinus, and after careful comparison of legs and antennæ mounted in balsam, the specimen was determined by the writer as *Hylastinus obscurus*. Scotch broom from the same locality and elsewhere has been examined several times since this discovery, but without finding any other borers or signs of their work. Furze, *Ulex europaeus*, has also been examined near Portland, Oreg., and Seattle, Wash., but no Hylastinus has been found upon this plant.

Swaine (*41, p. 73*) recorded the occurrence of this species on "White Dutch clover, and sainfoin (cutting tunnels but not breeding) in Canada." Bedel (*2*), Nördlinger (*33, p. 234*) and Chapman (*6*) recorded *Hylastinus obscurus* as a stem miner on (*Spartium*) *Cytisus scoparius;*

[10] In correspondence, published by Professor Lovett's permission.

Chapman (*6*) on *Ulex europaeus*; Cecconi (*5, p. 160*) on *Cytisus alpinus;* and del Guercio (*16, p. 264*) on *Cytisus laburnum.* Bedel (*2*) found it also on an old, woody root of *Ononis natrix,* exposed on the side of a bank. Some of the records on Cytisus may refer to *Hylastinus fankhauseri* Reitter (*36, p. 280*) rather than *H. obscurus,* but are retained here for reasons stated on page 3.

DAMAGE

FIRST CROP YEAR

The earliest injury to new clover (first crop, seeded the previous year) is observed in the spring a week or two after the time of the first migratory flight. The females at this time are busily engaged in making the first egg galleries, and the males are feeding, usually in grooves on the crowns. The simultaneous attack of five or six root borers on one small root often girdles it, causing wilting and early death of the plant. This injury first appears late in April or in May.

A fungous disease, caused by *Sclerotinia trifoliorum* Erik. (*14*), is prevalent at this season, and in the Pacific Northwest for several months preceding, and may easily be mistaken for this injury. Injury caused by this fungus differs from root-borer injury in that the several stems of the diseased clover plant usually wilt at different times. Often a few stalks of the plant remain normal, while infected stalks are stunted and killed back to the crown. In the case of injury by root borers all the stems of the plant usually wilt at the same time. An examination of plants affected by the fungus will also show discoloration of the stems and often, on dead stalks, a thin whitish fungous growth.

In new clover no further injury is usually noted until haying time, when, in case of severely attacked fields, many plants are broken off at the crowns by the mower. This is often the first injury observed. Toward the end of July, when the new second growth is well up, a severely infested field shows many sickly and dead plants and the seed of ripe heads is often withered and light. In one case observed a 5-acre field of clover in its first crop year had been destroyed by the end of July, 1914. Early the next spring the ground was bare except for weeds and the dried dead stems of the second hay crop, which had not been worth cutting. At this time the clover roots in this field had been almost completely consumed by the borers; the dried stems had fallen or were sticking out of the ground, attached to small pieces of clover crowns which the hordes of borers were rapidly consuming. This severe and unusual damage was attributed to the fact that a 40-acre field of old clover about one-quarter of a mile away had been plowed in April, 1914, and borers leaving this field in large numbers had migrated and concentrated on this small field with fatal results. A similar case was noted by Davis (*9, p. 47*) in July, 1893, the clover being of the mammoth variety. Cases of complete destruction of a clover stand have also been reported from the States of Indiana, Ohio, and New York. Severe injury to red clover in the first crop year is likely to occur whenever near-by fields of old clover are plowed in the spring.

Usually, however, the injury to young clover consists of a gradual dying of the plants during July, August, and September. The plants that are most severely infested and die first (in July) set light and

withered seed, but plants killed later in the summer may have set good seed. This injury late in summer and in the fall is due to the feeding of the rapidly maturing larvæ and the young adults (fig. 13). Injury is greatly enhanced by drought, and the extent and severity of the injury often seem directly related to the fertility, or at least the physical state, of the soil.

FIG. 13.—Red clover roots, showing root borers and injury caused by them

All the plants on four separate areas taken at random in a field at each of several places in Washington County, Oreg., the four areas in each field amounting in all to one ten-thousandth of an acre, were dug up, taken to the laboratory, and carefully examined to determine the extent of the damage done to them by clover root borers. The results are presented in Table 6. The record indicates considerable diversity in thickness of stand and brings out the more severe injury to clover on the poorer soil of the first field noted. Where clover fields are left for a second crop, the table indicates that the stand is, under the most favorable conditions, reduced approximately 50 per cent by the second season. When there is a good stand originally, a fair crop of hay may be obtained in the second season, and in a favorable season some seed may be harvested.

TABLE 6.—*Extent of damage done by clover root borers in selected areas in Washington County, Oreg.*

COUNTS ON CLOVER OF FIRST CROP YEAR, ONE TEN-THOUSANDTH OF AN ACRE

Date collected	Number of plants	Condition of plants					Place	Soil type[1]
		Uninfested	Infested	Alive and strong	Weak	Dead		
1921								
Sept. 27	36	0	36	6	17	13	Verboort	Amity silt loam, undrained.
Sept. 26	62	17	45	16	16	13	Hillsboro	Amity silt loam, tile-drained.
Sept. 29	45	11	34	11	10	13	Forest Grove	Chehalis silt loam.

COUNTS ON CLOVER OF SECOND CROP YEAR, ONE TEN-THOUSANDTH OF AN ACRE

Sept. 24	53	0	53	5	25	23	Forest Grove	Melbourne loam.
Sept. 27	37	0	37	7	15	15	do	Chehalis silt loam.

[1] Soil Survey of Washington County, Oreg., by E. B. Watson, in charge, and E. C. Eckman, of the United States Department of Agriculture, and A. L. Fluharty and C. V. Ruzek, of the Oregon Agricultural Experiment Station. Bureau of Soils, Washington, 1923.

SECOND CROP YEAR

The count indicates that, under severe infestation, unless the field is self-seeded there will be practically no clover left at the end of the second crop year. In the second crop year the clover is sometimes killed out after the hay crop is harvested, no further cutting for hay or seed being possible.

It has been the general practice in the Pacific Northwest, and is still so to some extent, to maintain clover fields for two crop years, and often for three (*23*), occasionally even for four, without plowing or reseeding. This probably was practicable in the early days, because of the scarcity of destructive clover insects and the continued self-seeding which replaced plants killed by animals, insects, and disease. However, land costs at present are so high as to lead progressive growers to keep their land as nearly as possible at maximum production. In the Willamette Valley the clover root borer is largely responsible for the fact that as a general rule more than one crop year of clover is no longer profitable.

The number of borers necessary to kill a root is not easy to determine, as many other factors are involved, such as the age of the clover, soil conditions, rainfall at critical periods, and attacks of other insects and fungous diseases. As many as 45 borers in various stages have been found on a single root, and 25 to 30 on a root are commonly observed in the severely infested field. Sixty-three borers of the new generation, 56 of them mature, in a cage where they had developed from eggs on the roots, killed 3 out of 5 roots by August 23; the 2 other roots were alive, 1 being uninfested. In another case 47 borers infested 3 out of 5 roots, and all roots were alive on August 23; only 1 root showed serious injury. In still another case 57 borers infested 2 out of 5 roots, and on August 26 1 of the 2 roots was still alive and looked fairly healthy with 26 young adults on it; but the root was so severely injured that it would probably have died before winter.

INJURY TO SEEDLING CLOVER

It has been commonly stated by entomologists and others that clover roots of less than a year's growth are not attacked by root borers. A field near Lebanon, Oreg., was seeded in April, 1915, to red clover, with a thin stand of oats as a nurse crop. When observed August 10, following, the clover had been noticeably damaged by clover root borers. The clover plants at that time were 12 to 14 inches high, and blossoming. The roots were less than one-fourth of an inch in diameter at the crowns. One larva, almost mature, was seen, indicating that development would be sucessful on some of these roots. An old clover field located across the road had been plowed in March. These two fields were in a long, narrow valley, bounded by wooded hills and crossed at intervals by small groves of trees, and the nearest other clover field was distant a mile up the valley. Root borers apparently had been forced to attack the young clover when the old roots of the plowed field dried out and the roadside clover in the vicinity had been killed. In another case 1 root in 20 was found infested by root borers June 10, 1918, in a field seeded in November, 1917. Young seedlings in old fields are not uncommonly attacked by adult root borers.

NATURAL ENEMIES

Very few natural enemies of the clover root borer are recorded in literature. Riley (*37*) recorded a soldier beetle larva, probably (*Telephorus*) *Cantharis bilineatus* Say, as predacious on the clover root borer. H. L. Parker has reared the soldier beetle, *Chauliognathus pennsylvanicus* DeG.[11] from "black velvety" larvæ which ate root borer larvæ. Adults were reared from "white slender naked pupæ slightly over one-half inch long" on November 18, 1914, and April 27, 1915.

In the Pacific Northwest the only natural enemy observed to attack the borers in the roots and on the ground was a fungous disease caused by the well-known entomogenous fungus (*Sporotrichum*) *Beauveria globulifera* Speg., as determined by the writer. This fungus attacks many ground-frequenting insects, whose spore-covered bodies are commonly found in clover fields. Root-borer adults are exposed to infection while above ground, moving from root to root, mating, and starting burrows. They are less likely to become infected while in mines in the root. This disease is most prevalent in the fall and spring, and any reduction in the number of root borers at this time, prior to the breeding period, is of economic importance. Larvæ and pupæ in mines in the roots are occasionally attacked by the same fungous disease. It appears to be very prevalent on low, wet, poorly drained land, and there are also indications that root borers on less-favored host plants are especially susceptible to the infection. The disease is certainly parasitic, as the cylindrical conidia and short sections of hyphæ have been found in the blood of living borers.

An attempt was made in April and May, 1920, to find bird enemies of the clover root borer at Forest Grove. Only those birds were killed, 53 in all and of 22 species, which were found near clover fields on days when it was known that the root borers were migrating by flight. On examination of their stomachs, 39 root borers were found

[11] Determined by J. A. Hyslop.

in the contents of 12 of them, representing 8 species of birds.[12] The 8 species, the number of each sex, if determined, and the number of root borers, if any, found in each stomach, are set forth in Table 7.

TABLE 7.—*Species and sex of birds in the stomachs of which root borers were found, with the number of borers in each stomach*

Species	Number of each sex			Root borers in each stomach
	Male	Female	Doubtful	
Streaked horned lark, *Otocoris alpestris strigata* Hensh.	1			1
Brewer blackbird, *Scolecophagus cyanocephalus* Wagl.	3	4		0, 0, 0, 0, 1, 0, 0
Oregon vesper sparrow, *Pœcetes gramineus affinis* Miller	5	1		0, 0, 0, 3, 0, 0
Townsend sparrow, *Passerella iliaca unalaschcensis* Gmel.		2		1, 0
Golden-crowned sparrow, *Zonotrichia coronata* Pall.			2	0, 1
Cliff swallow, *Petrochelidon lunifrons* Say	3	1	1	13, 4, 0, 9, 1
Northern violet-green swallow, *Tachycineta thalassina lepida* Mearns	2	1		1, 2, 0
Pacific house wren, *Troglodytes ædon parkmanii* Aud.	1			2

CONTROL

The mode of life of the clover root borers, which for most of their comparatively long lives are confined to the interior of the host roots, spending but a short time above ground, renders extremely difficult the application of any immediately effective control measures. The statement of Hopkins (*21, p. 31*) referring to the futility and needlessness of efforts at complete extermination of the bark beetles of the genus Dendroctonus seems applicable also to the clover root borer. Repressive measures tending to reduce the numbers of this insect pest seem to be sufficient to reduce its injury to a negligible minimum. The ability of the adult borers to migrate considerable distances at the time of the spring flight indicates that, to be appreciably effective, any effort at control must be initiated on a community or regional basis and may involve a change in customary farm practice. The one hopeful fact brought out by the investigation is that the species is a comparatively slow breeder, and this indicates that continued repressive measures should have a cumulative effect and eventually should result in freeing a severely infested clover section from serious root-borer injury. Field observations, in various regions differing widely in farm practice, bear out this conclusion. Data bearing on possible control measures have been collected from experiments performed, and from field observations on the results of different methods of farm practice in various parts of the Willamette Valley.

CONTROL EXPERIMENTS

1. To test the effect of heat and drying on clover root borers, roots were dug from a field on August 22, 1916, and some of them placed on the surface of the ground and some lightly buried (to a depth of about one-half inch) in a spaded plot. Eighty per cent of the borers were in the pupal and prepupal stages. The temperature rose as high as 98° F. in the shade. Two days later the roots were very dry and hard, and all stages of the borers were dead, except that one fully hardened adult escaped to the outside of a root.

[12] Skins determined by W. A. Shaw, of Washington State College, Pullman.

2. A strip in a badly infested clover field in its second crop year was plowed 8 inches deep and disked six times on August 28, 1917. Borers in all stages were present, approximately 20 per cent of them being new, soft adults; only one fully hardened adult was seen. The ground was very dry and hard, and plowed in large clods very difficult to work up. Flight screens were erected to determine if the borers flew from the plot. On September 5 all the borers, even adults near the outside of the roots, were dead in the dry, hard roots lying on the surface of the ground, or covered by an inch or less of dry soil; some exit holes, however, indicated the escape of a few root borers. Deeply buried roots were still moist, and contained living root borers in larval, pupal, and adult stages. On September 15 a count on several roots collected from the surface and beneath it to a depth of 2 inches showed 70 per cent dead. Living larvæ, pupæ, and adults were usually on roots which were partly rotten, soft, and punky. On November 8, living adults were found on two roots buried 4 to 5 inches deep. Some time between September 15 and November 8 screens caught two borers flying from this plot. The maximum temperature during the first 10 days following the plowing of this plot was 86° F. Precipitation began on September 6.

3. A small field seeded in May, 1916, was plowed and harrowed with a spring-tooth harrow on August 2, 1918. The ground was very dry and hard and worked up many hard clods. The spring-tooth harrow worked fairly well in raking the roots to the surface, with the exception of those deeply buried. The cultivation was as good as the average farmer could accomplish at this season. Ten roots were found to contain 70.5 per cent of larvæ, 20.8 per cent of pupæ, and 8.7 per cent of adults, there being in all 149 borers.

On August 10, 50 per cent of the borers in 10 roots gathered from the surface were still alive. The roots were dry and hard on the outside, but the interiors usually were not yet hard. The weather had been cloudy, with light precipitation since the plowing.

On August 20, 10 roots collected from the surface contained 47 dead larvæ, 12 dead adults, and 1 living larva, or 98.3 per cent of all were dead. Since the last examination the temperature had reached 90° F. on one day.

On October 7 several buried roots were examined, most of them being dried up, with no living borers. Live adults were found on two roots which were badly decayed, and therefore soft.

On March 29,1919, a few adults were swept from this plot, more than three weeks before the time of their normal flight; many were coated with mud from the hard treatment they had received. On July 23, a dead adult was found in a groove eaten into a wheat stem. Evidently the insect had been driven to abnormal activity by the plowing of the clover.

Webster (*46*) performed a similar experiment at Wooster, Ohio, in 1899. In this case the plot was plowed on July 8, about nine days before the first occurrence of pupæ in the field. On August 10, living larvæ and pupæ were found on roots buried from 3 to 5 inches below the surface. On October 19, a rather thorough examination of the plot resulted in the finding of only four living beetles on buried clover roots.

FIELD OBSERVATIONS

Observations were made on clover fields plowed in December, January, February, and March in various parts of the Willamette Valley. In all these cases root borers were found alive on buried roots up to the time of the spring flight, and in some cases there was only a small percentage of mortality among the beetles in roots not buried by the plow. In April and May great numbers of beetles were observed migrating from some of these fields.

A field of old clover on creek-bottom land was plowed August 31, 1920. Rainy weather began September 1, and there was an unusual amount of precipitation throughout the late summer, fall, and winter. On February 26, 1921, a few living root borers were found on roots fully exposed on the surface of the ground. Many dead borers were also found, a large proportion of them showing a fungous growth.

A field which had been seeded in June, 1914, was turned under for green manure, without harrowing, about June 4, 1915. Most of the roots were completely upended and buried, except for their tips. On June 26 the roots were still infested by borers, there being present adults, larvæ, and eggs. Several adults were found which had been killed by fungus. Ten months after plowing, on April 4, 1916, living adults, which must have matured from eggs laid on the turned-under clover roots, were found on the moist, rotting crowns of buried roots, although many of the clover roots had completely rotted away.

Part of a field was plowed and harrowed in late June or early July, 1915. On August 13, the roots on the surface of the ground were hard and dry and on them were many dead borers, but none living. On October 7 no living borers in any form were found on the roots. Remains of larvæ and pupæ were found dried up in their mines, and new adults were found dead and imprisoned in groups in the centers of the dried roots, which were so hard as to turn the edge of a knife. Now and then a beetle had died after forming an opening to the exterior, but one not large enough to permit emergence. The roots had dried so rapidly that the beetles were unable to gnaw their way out before death overtook them.

A study of these data indicates that where clover sod is plowed and the roots harrowed out in the period between June 15 and August 1, a large percentage of the borers are killed, provided the weather is hot and dry after the plowing. Borers on roots that are deeply buried by this treatment often survive, so that complete extermination in a field is rarely if ever possible. No experiments were performed in an irrigated region, but the writer is convinced that summer plowing of clover and subsequent withholding of irrigation water would be very effective under irrigation conditions.

The data presented also show that the percentage of mortality among the borers is increased by plowing in late summer and early fall, because of the exposure of the borers to an unfavorable environment on the plowed-up roots. A disturbance of the normal activities of the clover root borers in the fall and early spring also results from this treatment, and undoubtedly interferes with the propagation of the pest in the following season. Unsuccessful attempts to secure offspring in cages started too early in 1919 (three weeks before the

first flight) showed that root borers, even when partially protected in a cheesecloth cage, are adversely affected above ground by rigorous weather in early spring. Considering the normally low rate of reproduction in this species, it is probable that a regular practice of early fall plowing in badly infested localities would progressively diminish the amount of infestation and eventually reduce the numbers of the pest to such an extent that little damage would occur to clover in the first crop year. Fall plowing would probably be especially effective in an irrigated region where the winter rainfall is light.

The data show that late fall or winter plowing has little effect as a control measure for the clover root borer. They also show and field observations very strongly emphasize, as Webster (*46*) and Davis (*9, p. 46*) have noted, that spring plowing of clover is absolutely ineffective in the control of the species, and may be a most harmful practice in the case of heavily infested fields. Such spring plowing causes the mature adults to leave the field almost simultaneously,

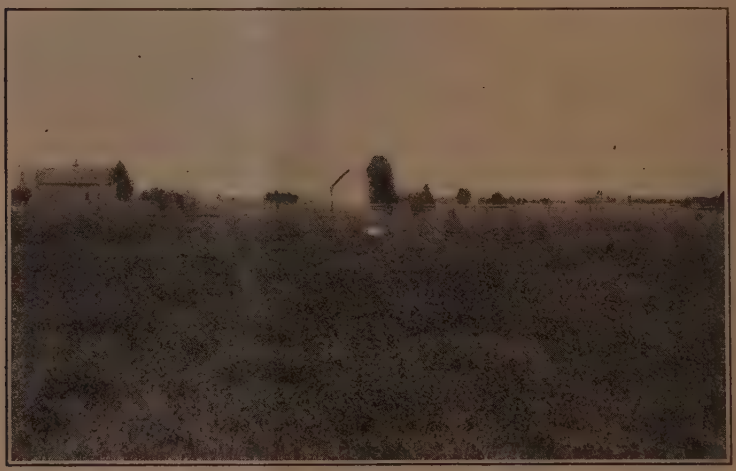

FIG. 14.—View of second-year clover field, showing weedy places where clover has been killed out by the root borer

and they may afterwards settle on any new clover in the vicinity in such numbers that the simultaneous attack of many borers will very seriously injure or utterly destroy it early in the season.

The practice of green manuring, at least under conditions prevailing in western Oregon, is shown to have little restraining effect on the clover root borer. Some of the insects are able to mature, even from eggs on clover roots which have been turned under. The only practicable way of killing root borers is by the drying and hardening of the roots; and in western Oregon this is possible only by harrowing out the roots in the summer or early in the fall of a dry season.

In some localities in western Oregon where the ranchers still attempt to follow the practice of maintaining clover fields for three or more years, root borers have for some time been extremely destructive. In other localities, where a one-crop system of clover culture is practiced, the insect has been appreciably reduced in numbers and no

longer occasions serious loss. The writer, after studying this problem in all its phases, is convinced that the early practice of allowing clover to stand over a considerable period is responsible for the tremendous increase of the insects in recent years in western Oregon (fig. 14). This opinion seems to gain some support from the apparent reduction in numbers of these insects since the reduction in the acreage of clover and the adoption of a short clover rotation, both brought about in many localities by war-time conditions.

A farm practice (*23, p. 5*) that has proved very successful in parts of Yamhill County, Oreg., especially on the lighter soils, is the seeding of clover either alone or with rape, in May or June, on well-prepared ground, and the subsequent pasturing of the clover during the late summer and fall of the same year and until about June 1 of the following year. The stock are then taken off and a seed crop obtained. Usually the clover is subsequently plowed up and seeded to grain, although occasionally it is maintained for another year. This practice, where generally followed, has reduced damage by the root borer and has also practically eliminated damage to the seed crop by the clover flower midge and the clover seed chalcid. The practice could be improved upon by less close pasturing during the year of seeding. It may happen that the clover is pastured so closely that the roots are kept small (*40, p. 91*) and therefore are injured more severely by a few root borers and clover root curculios (*Sitona hispidulus* Fab.) than if they had made a larger, more vigorous growth.

The practice of cutting the first crop of clover early for hay, as recommended for the control of the clover flower midge, would also tend to reduce injury to the seed crop by the clover root borers, as, except in case of an unusually heavy infestation, the clover seed would mature before any large number of clover plants would be killed by their work.

There are many good reasons why clover should not be left undisturbed for a number of years. Not only does such treatment permit the increase of root borers, but all kinds of clover insects multiply rapidly in old fields, especially root curculios, clover leaf weevils, cutworms, grasshoppers, leafhoppers, plant bugs, and aphids. Young clover, seeded into the following year's wheat crop, is often severely injured by some of these insects when it has been preceded by clover sod of some years' standing. Vetch sown on old clover sod is often more or less severely injured by clover root borers and curculios. Old clover fields in western Oregon also become breeding places for rodents, which are often destructive to clover and other crops. Figure 15 illustrates the damage in a clover field in its second crop year by root borers, grasshoppers, and rodents.

FERTILIZER

Davis (*9, p. 46*) experimented with large quantities of commercial fertilizer as a possible repellent for the clover root borer, finding that such heavy applications had no apparent effect on the root borers but often severely injured the clover.

The writer tried applications of phosphatic fertilizers to clover, hoping to induce more rapid root growth. The plots of experiments at Corvallis, Oreg., conducted by the Bureau of Plant Industry in cooperation with the Oregon Agricultural Experiment Station, were also available for study. From these sources no definite conclusions

could be drawn regarding any difference in infestation of the various plots by clover root borers. These experiments, however, indicated that the growth of the clover, both in roots and tops, was considerably stimulated by applications of acid phosphate, even on fertile bottom lands. The plots at Corvallis manifested a similar stimulation by both acid phosphate and gypsum.

FIG. 15.—Damage to clover, in its second crop year, by clover root borers, grasshoppers, and rodents

REPRESSIVE MEASURES RECOMMENDED

Adopt a one-crop system of clover culture throughout the community.

Plow clover sod as soon as possible after seed harvest or second hay crop.

Plow and harrow badly infested clover sod after the hay crop in late June or July; a plow making a flat furrow and a spring-tooth harrow serve best for harrowing out as many roots as possible.

Never plow badly infested clover sod in early spring; early and severe damage may be caused to neighboring young clover.

Cut clover early for hay, in case of an early infestation by the root borer, in order that as many plants as possible of the second crop may mature seed before being killed by root borers.

Adopt any agricultural practice that makes for a healthy, rapidly growing root system, such as good seed from a locality known to produce a good strain of red clover; provide a good seed bed and good drainage; maintain in the soil the elements required for optimum growth of the plant. Root borers do not thrive as well on rapidly growing, sappy roots as on those the growth of which has been checked.

SUMMARY

The clover root borer is an insect of wide distribution throughout the world, wherever red clover is an important crop.

It belongs to a group of beetles which are commonly found attacking injured or weakened woody plants.

The clover root borer feeds most commonly upon the roots of red clover. It is one of the principal factors limiting the life of a clover stand after the first crop year, and even in the first crop year has frequently caused large losses of hay or seed.

The beetles migrate from old clover to new clover fields on favorable days in April, May, and June, the maximum flight usually occurring in May.

The eggs of this insect are laid in niches in the walls of burrows in clover roots, beginning late in April or in May, and hatch in 17 to 30 days. Comparatively few eggs, probably seldom more than 20, are laid by each female.

The larvæ develop slowly, and the first pupæ are not found until about the middle of July. The pupal period lasts from 8 to 13 days.

As the egg-laying period of each female extends over a considerable length of time, there is at all times a great diversity in the stage of development of the root borers.

New adults are not numerous before the middle of August, although the first new adults are found about the middle of July.

Some larvæ are still immature when winter arrives, and do not pupate and transform into adults until April or May of the following year.

The total developmental period from egg to adult is not less than 60 days and may be 90 days or more. The total life span of the individual borer may be a year or even longer. There is but one generation a year.

The borers pass the winter in the roots where they mature.

The development of the clover root borer and the damage caused by it are influenced by climatic and soil factors, by the condition of the host plant, and by topography.

The most noticeable damage to red clover by the clover root borer is observed in the second crop year, when the stand may be so badly thinned as materially to reduce the crop. Often by late summer the stand is practically killed out unless there has been abundant self-seeding.

In regions where root borers are very abundant serious injury may be done to the crop in the first crop year. Young clover fields may be entirely killed out soon after the first hay crop, when such fields are situated near badly infested clover sod which has been spring plowed.

Red clover is occasionally attacked even in the year of seeding.

Alsike clover is not usually seriously injured by clover root borers.

Injury to peas and vetch may occur when these crops are grown near badly infested old clover fields.

Clover root borers have been found on alfalfa plants, but there is probably little danger that alfalfa will be generally or seriously attacked.

The clover root borer has but few natural enemies; an entomogenous fungus, eight species of birds, and the larvæ of predacious beetles have been recorded as preying on the species.

Clover root borers can be killed in large numbers by plowing up badly infested clover roots and harrowing them to the surface of the soil, at any time between the middle of June and the beginning of August.

Many root borers may be killed by plowing and harrowing clover soon after the seed crop or second cutting of hay. This practice also induces an abnormal activity of the surviving root borers in the fall and early spring, which is detrimental to their successful propagation.

Late fall and winter plowing and the practice of green manuring have little restraining effect on the clover root borers.

Spring plowing of heavily infested clover sod has no remedial value and may cause severe damage to new clover in the vicinity.

Serious injury to clover in the first crop year may be avoided by cooperation of the community in farm practices which will reduce the numbers of the root borers to a point where they can not aggressively attack the clover. A one-crop system of clover culture, together with a general practice of early fall plowing of clover sod, and, in exceptionally severe cases, summer plowing and harrowing, should free a community from appreciable damage by the clover root borer in the first crop year.

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